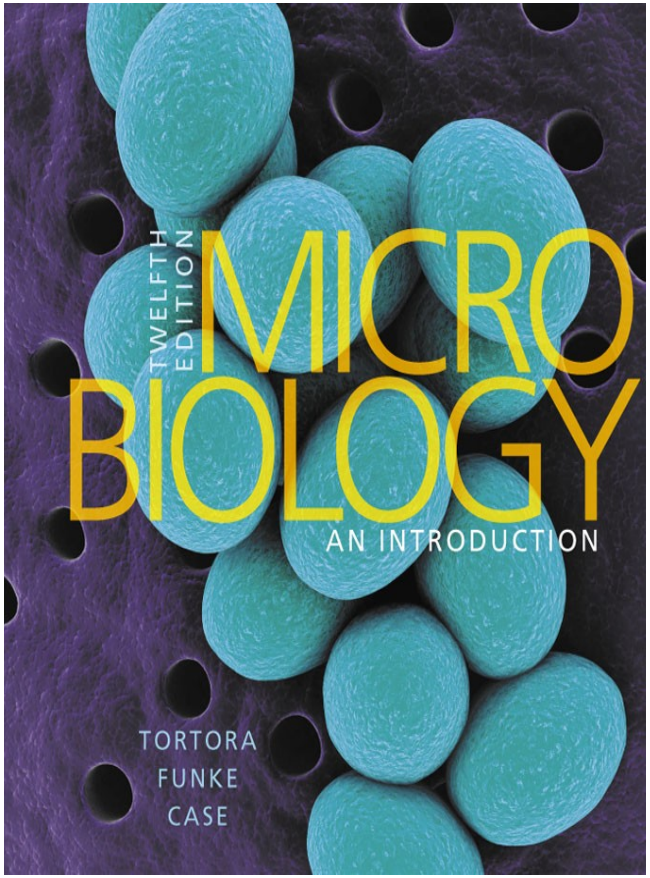
Microbiology an Introduction

Twelfth Edition

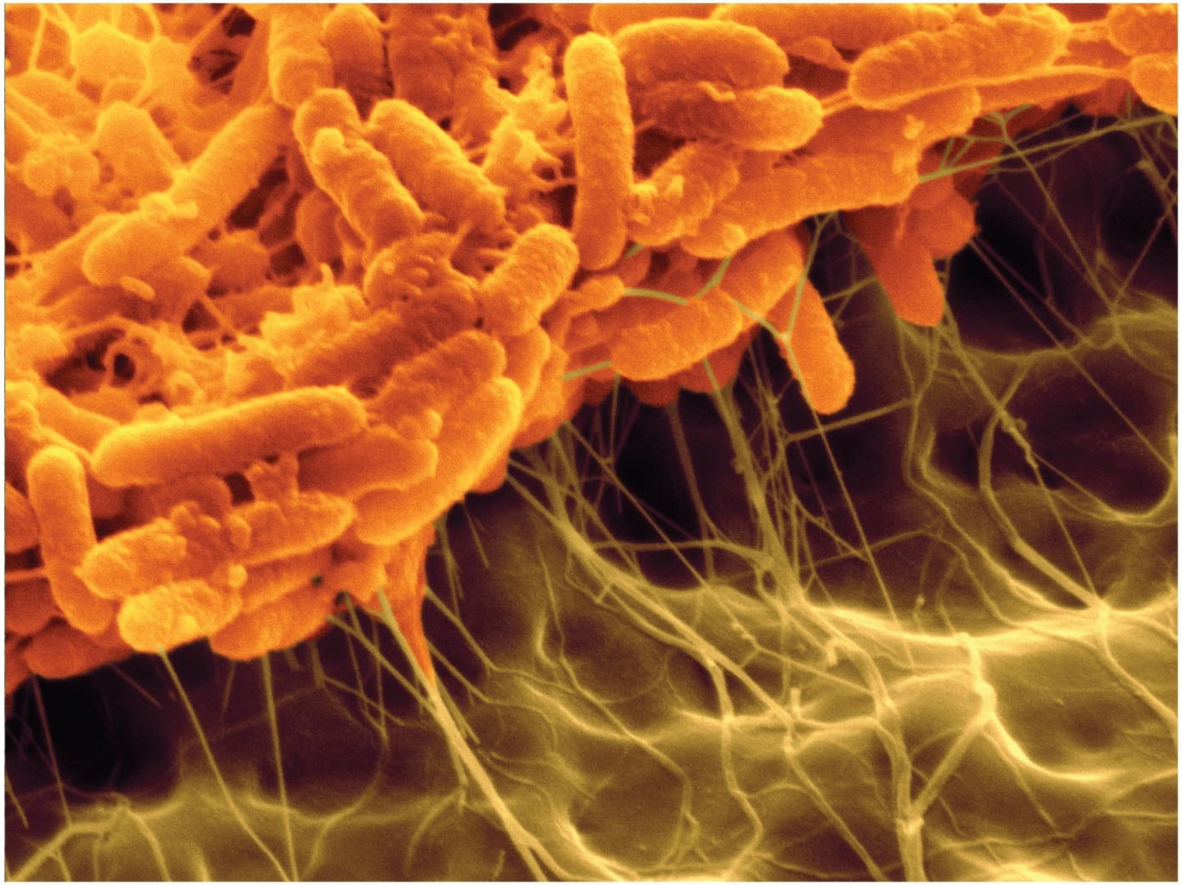


Chapter 4

Functional Anatomy of Prokaryotic and Eukaryotic Cells

Pearson

Serratia Bacteria



Comparing Prokaryotic and Eukaryotic Cells: An Overview (1 of 3)

Learning Objective

4-1 Compare the cell structure of prokaryotes and eukaryotes.

Comparing Prokaryotic and Eukaryotic Cells: An Overview (2 of 3)

- **Prokaryote** comes from the Greek words for prenucleus.
- **Eukaryote** comes from the Greek words for true nucleus.

Comparing Prokaryotic and Eukaryotic Cells: An Overview (3 of 3)

Prokaryote

- One circular chromosome, not in a membrane
- No histones
- No organelles
- Bacteria: peptidoglycan cell walls
- Archaea: pseudomurein cell walls
- Divides by binary fission

Eukaryote

- Paired chromosomes, in nuclear membrane
- Histones
- Organelles
- Polysaccharide cell walls, when present
- Divides by mitosis

Check Your Understanding-1

Check Your Understanding

- ✓ What is the main feature that distinguishes prokaryotes from eukaryotes?
  4-1

The Prokaryotic Cell

Learning Objective

4-2 Identify the three basic shapes of bacteria.

The Size, Shape, and Arrangement of Bacterial Cells
(1 of 4)

- Average size: 0.2 to 2.0 µm diameter × 2 to 8 µm length
- Most bacteria are monomorphic (single shape)
- A few are pleomorphic (many shapes)

The Size, Shape, and Arrangement of Bacterial Cells

(2 of 4)

- Bacillus (rod-shaped)
- Coccus (spherical)
- Spiral
  - Vibrio
  - Spirillum
  - Spirochete
- Star-shaped
- Rectangular

Figure 4.4 Spiral Bacteria

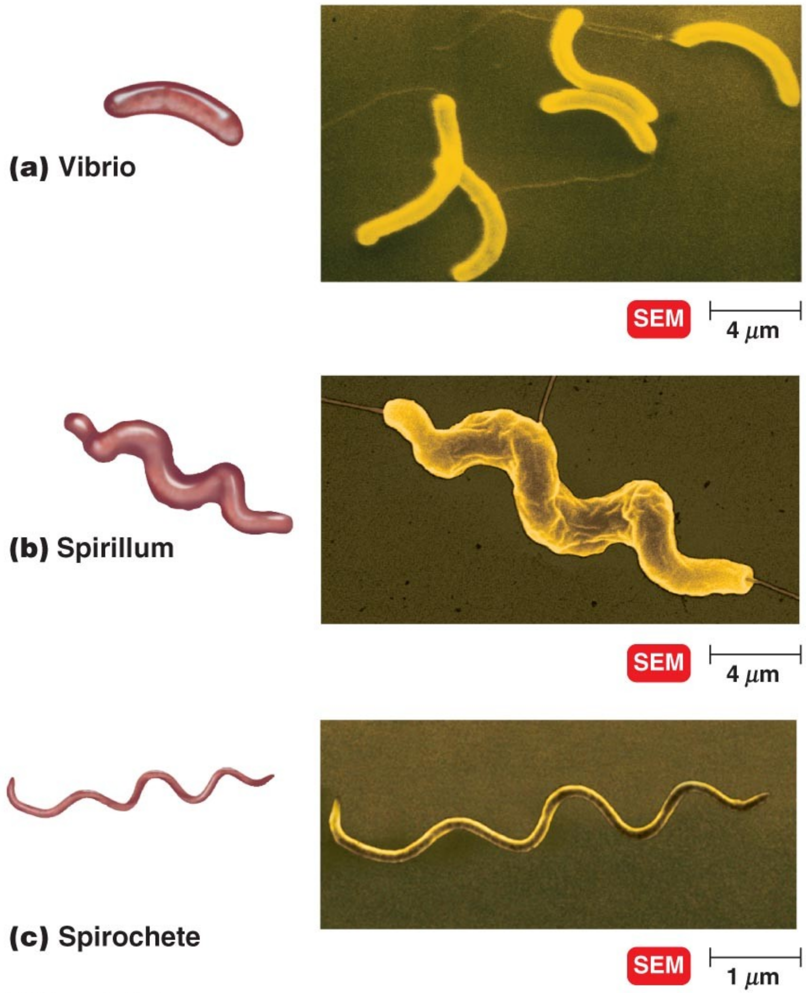
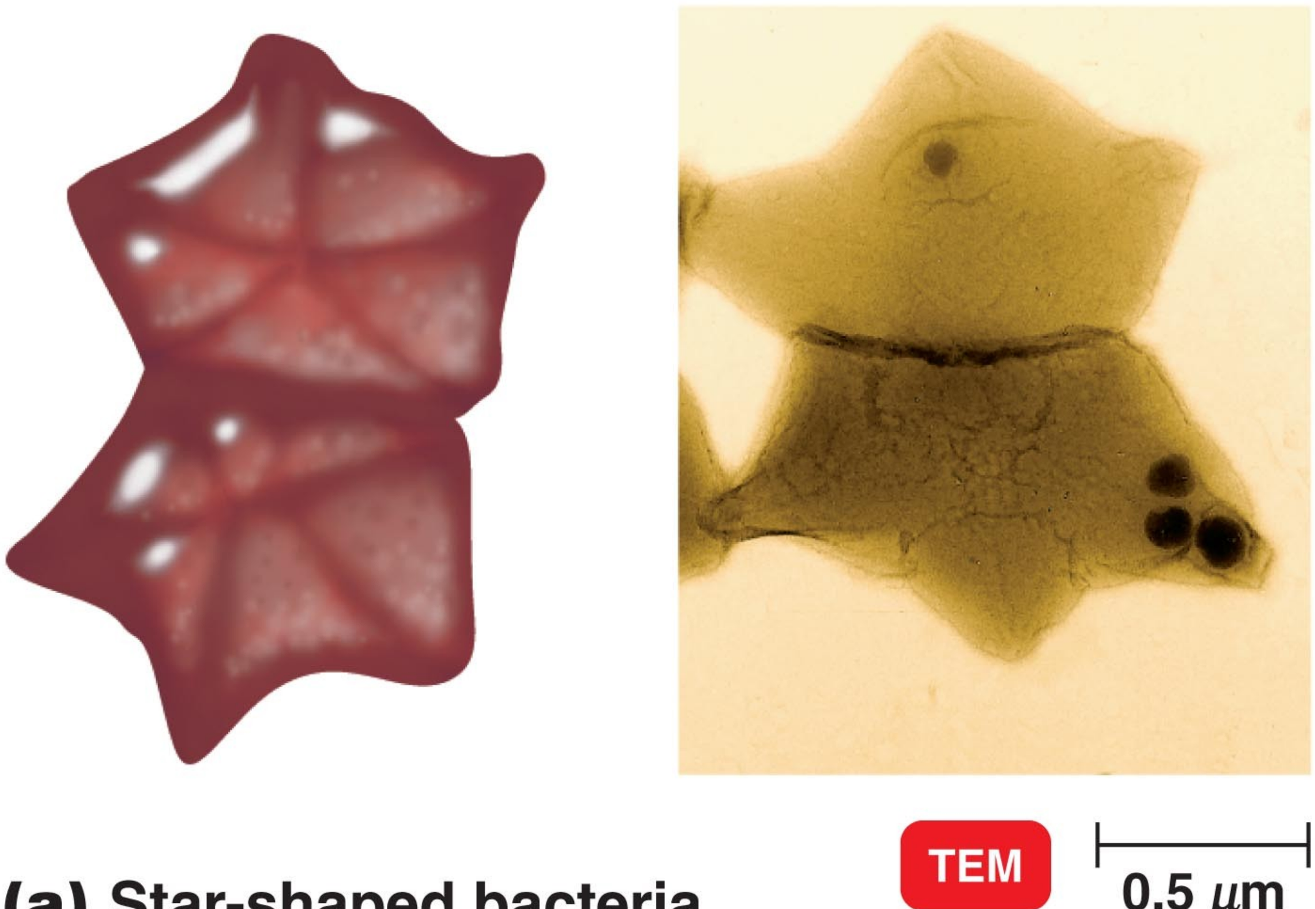
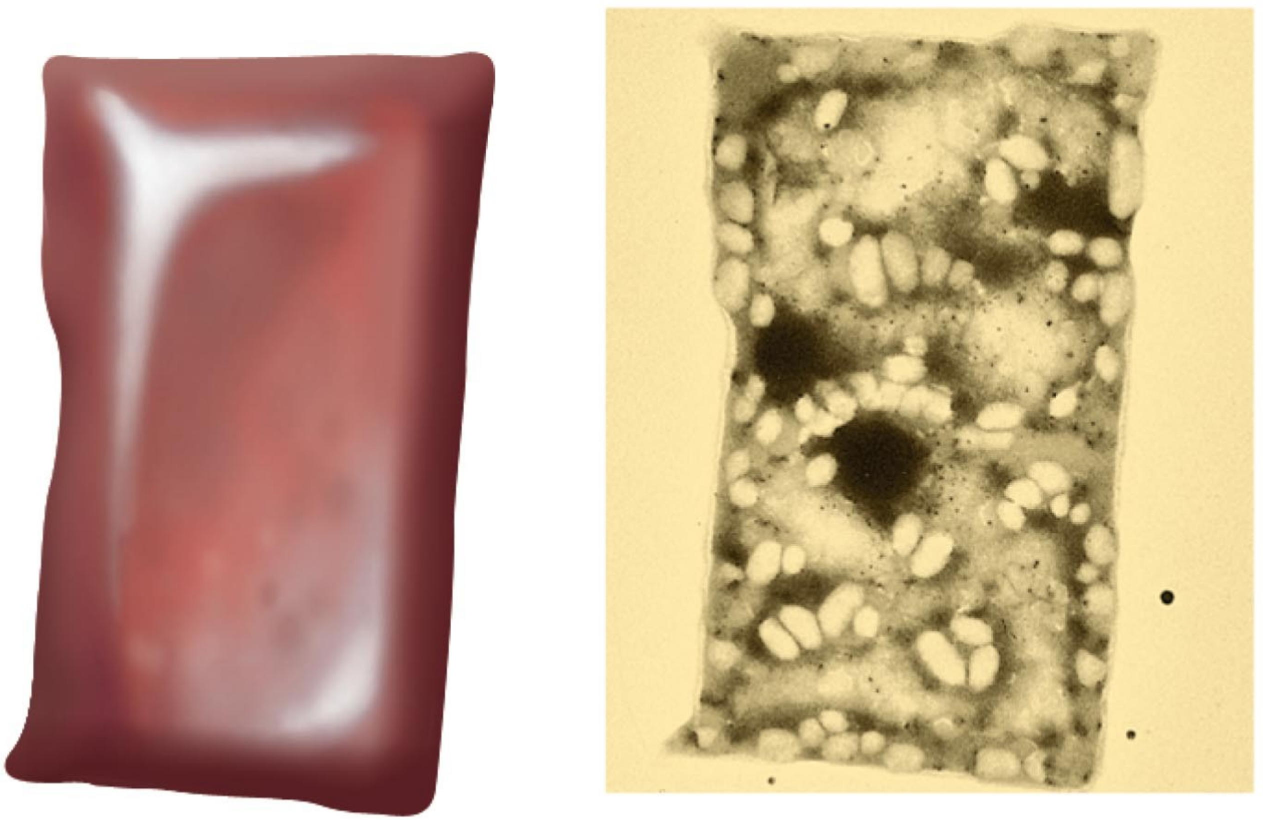


Figure 4.5a Star-Shaped and Rectangular Prokaryotes



(a) Star-shaped bacteria

Figure 4.5b Star-Shaped and Rectangular Prokaryotes



(b) Rectangular bacteria

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The Size, Shape, and Arrangement of Bacterial Cells (3 of 4)

- Pairs: **diplococci, diplobacilli**
- Clusters: **staphylococci**
- Chains: **streptococci, streptobacilli**
- Groups of four: **tetrads**
- Cubelike groups of eight: **sarcinae**

Figure 4.1 Arrangements of Cocci

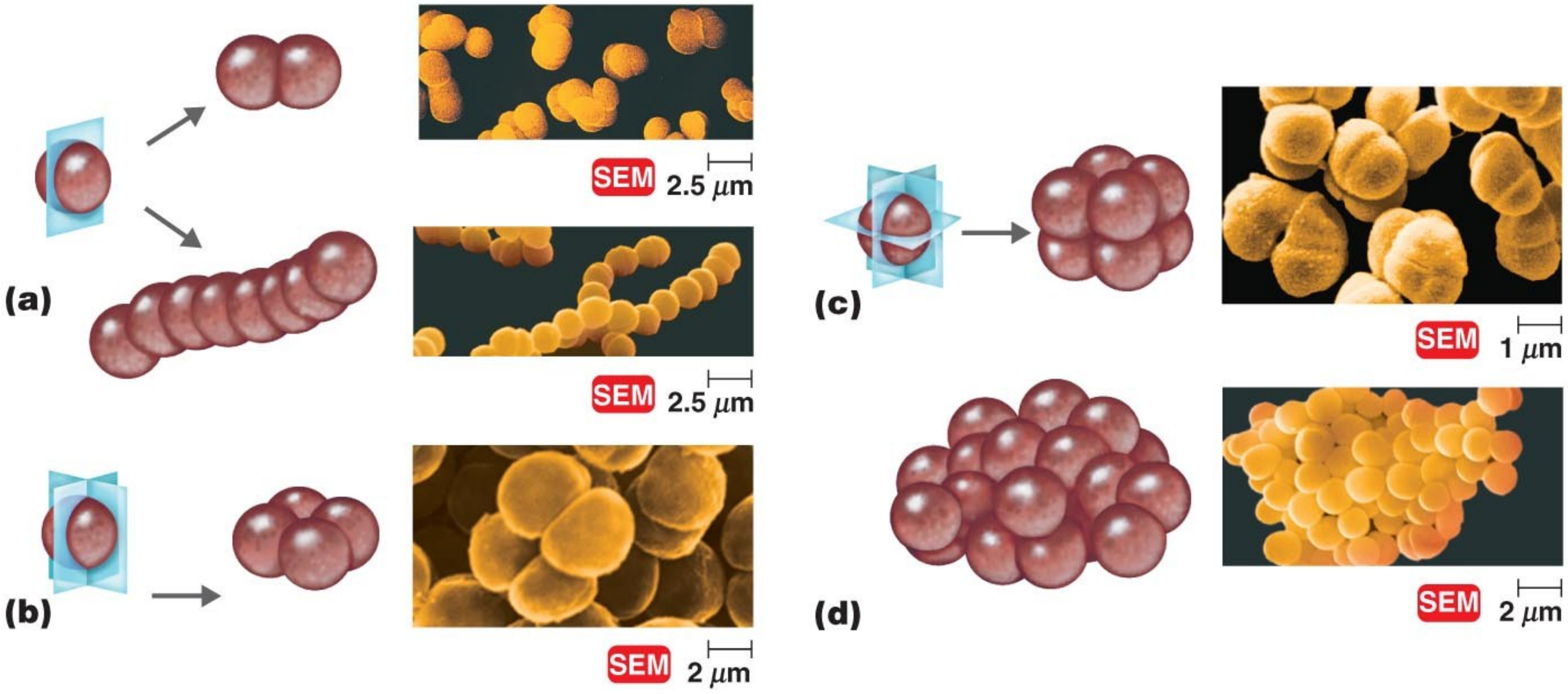


Figure 4.2a-d Bacilli

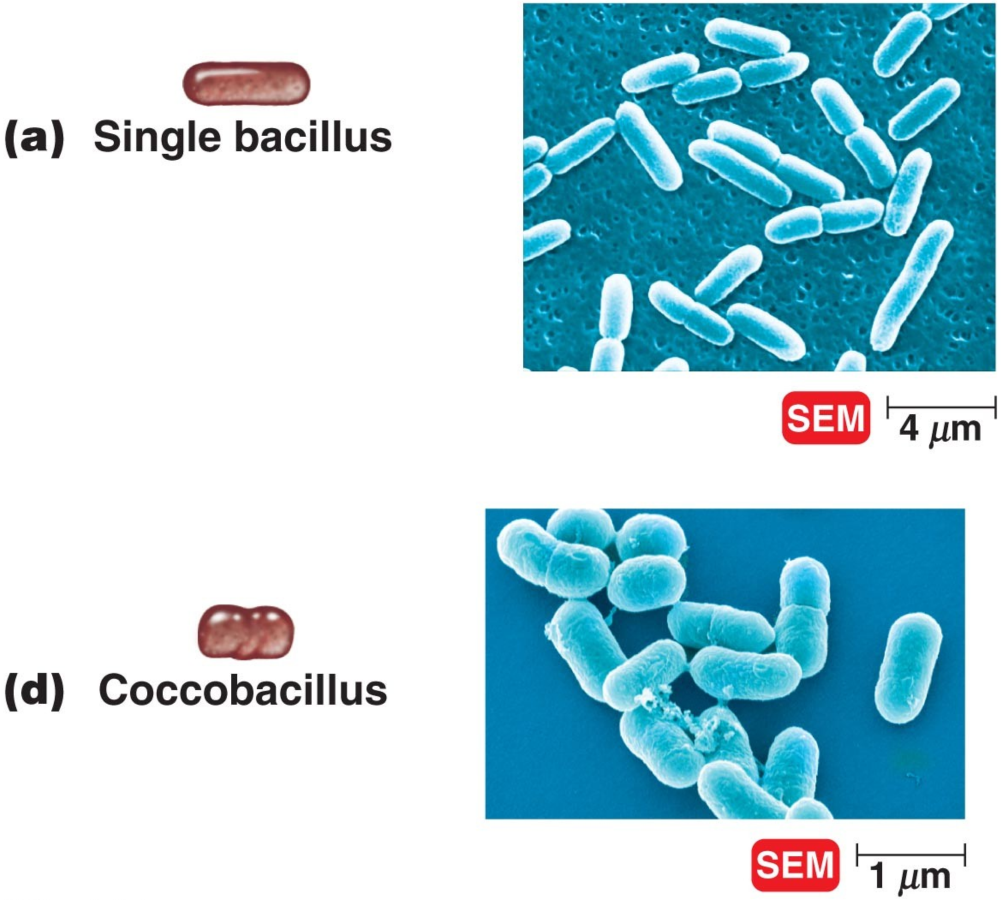
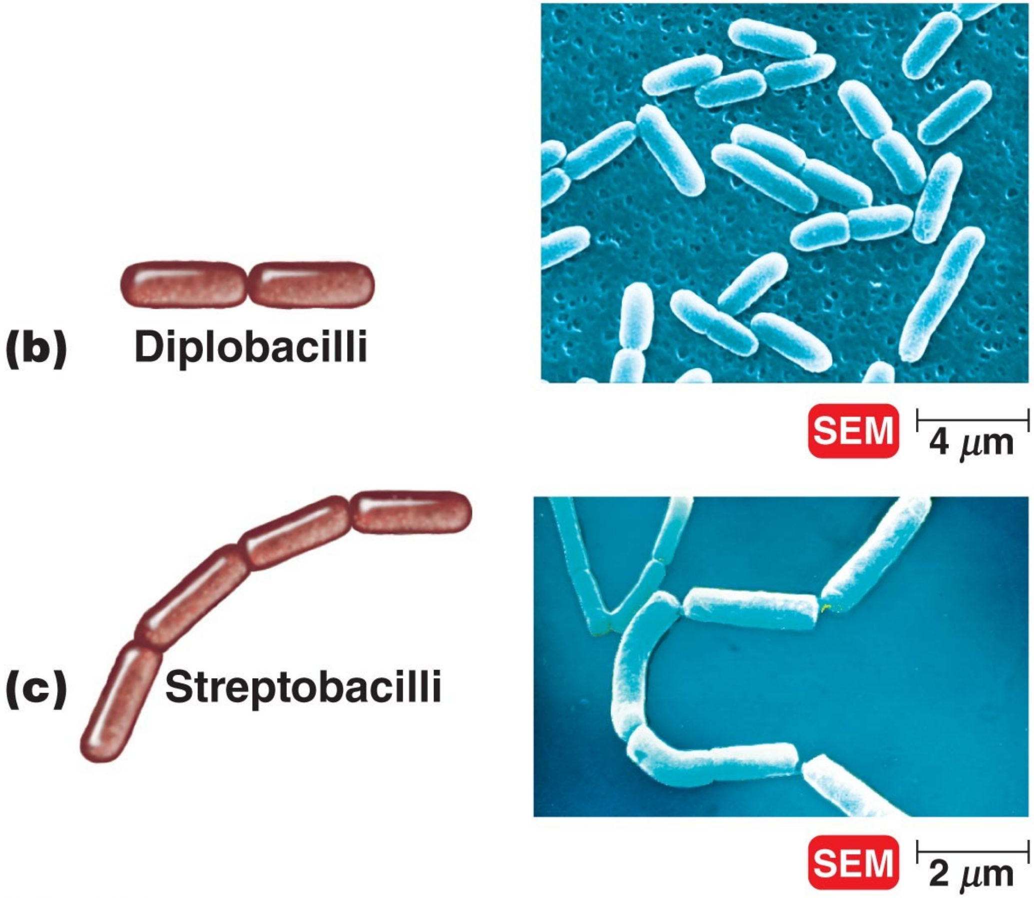


Figure 4.2b-c Bacilli



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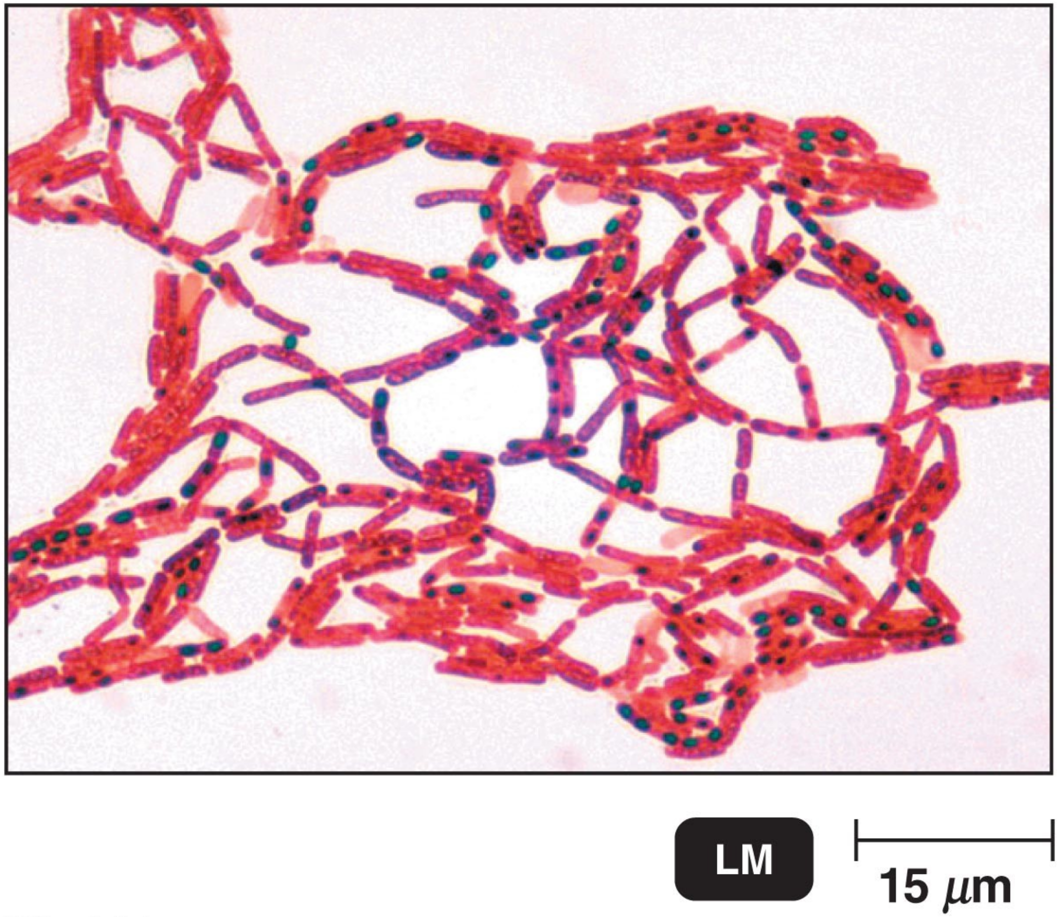
The Size, Shape, and Arrangement of Bacterial Cells

(4 of 4)

- Scientific name: **Bacillus**
- Shape: bacillus

Figure 4.3 Gram-Stained Bacillus Anthracis



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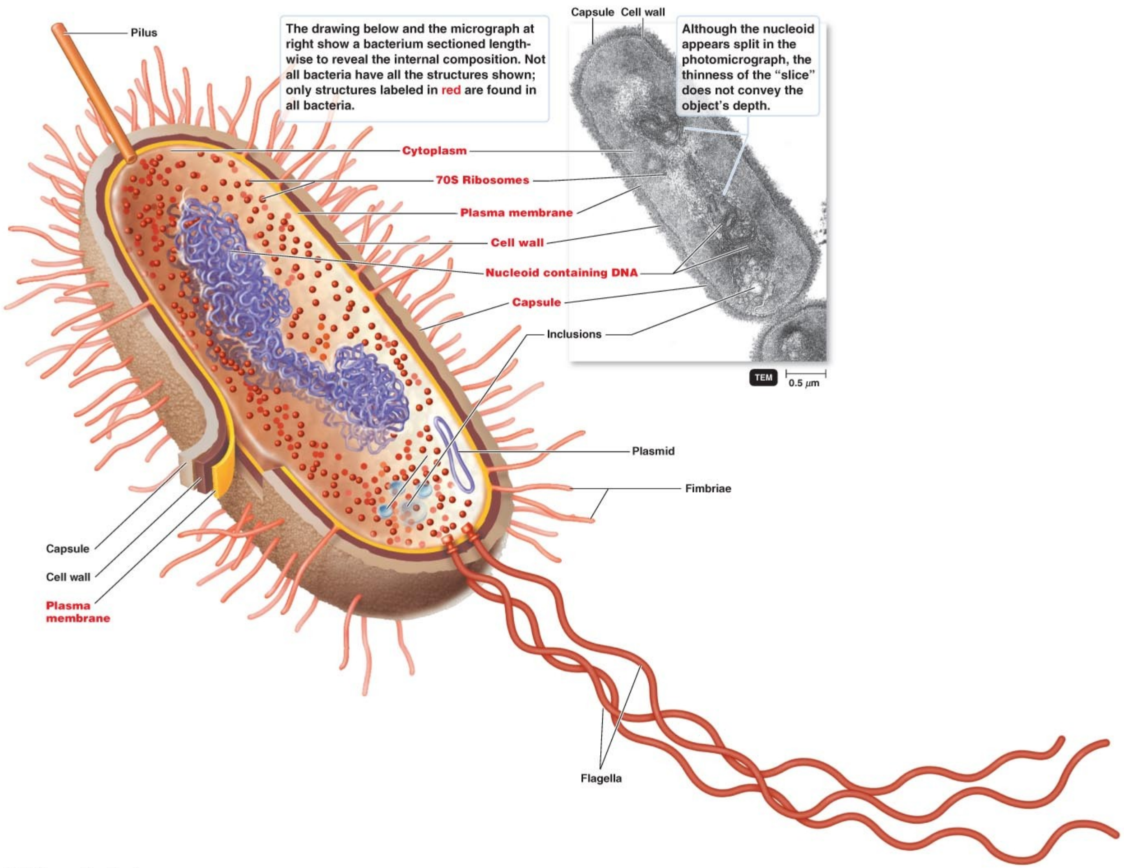
Check Your Understanding-2

Check Your Understanding

- ✓ How can you identify streptococci with a microscope?
  4-2

Figure 4.6 The Structure of a Prokaryotic Cell (1 of 2)



Structures External to the Cell Wall

Learning Objectives

4-3 Describe the structure and function of the glycocalyx.

4-4 Differentiate flagella, axial filaments, fimbriae, and pili.

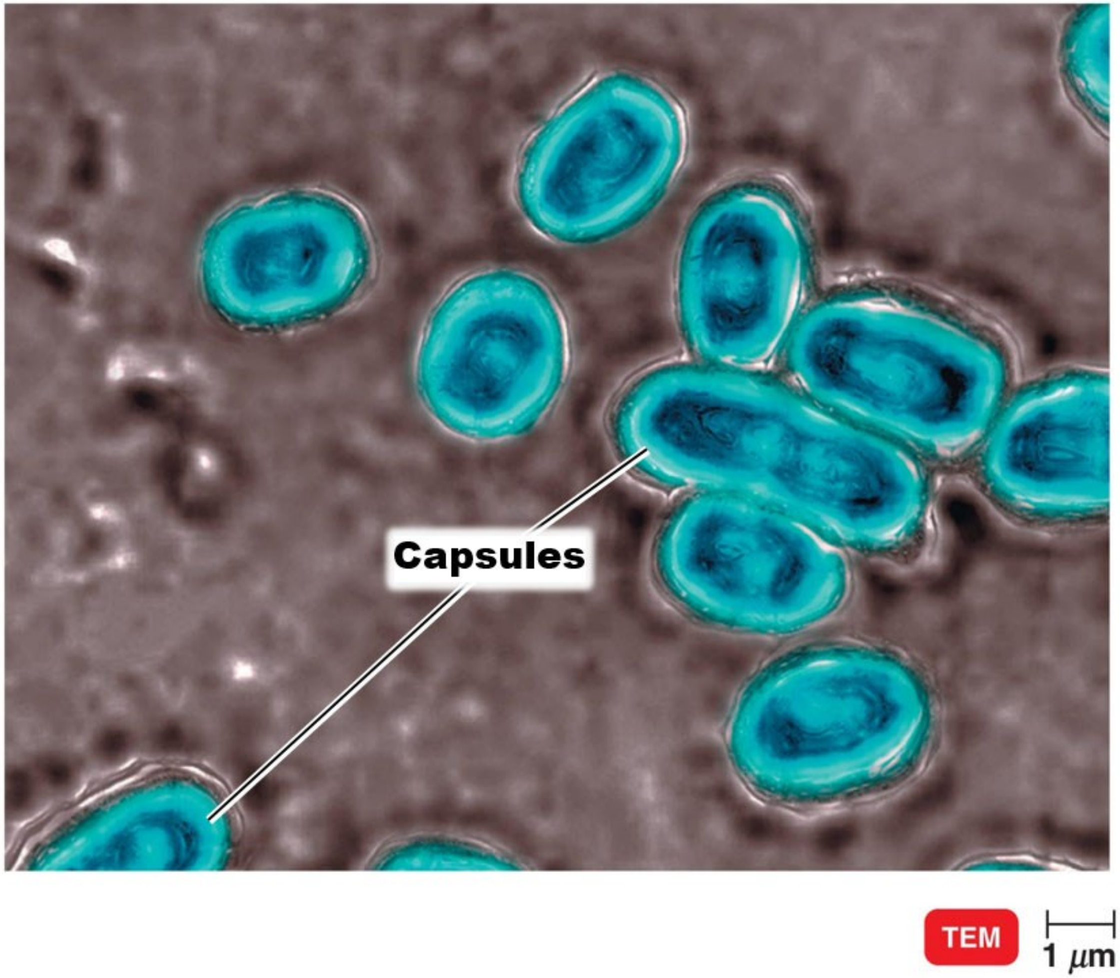
Glycocalyx (1 of 2)

- External to the cell wall
- Viscous and gelatinous
- Made of polysaccharide and/or polypeptide
- Two types
  - **Capsule:** neatly organized and firmly attached
  - **Slime layer:** unorganized and loose

Glycocalyx (2 of 2)

- Contribute to virulence
  - Capsules prevent phagocytosis
  - Extracellular polymeric substance helps form biofilms

Figure 24.11 Streptococcus Pneumoniae, the Cause of Pneumococcal Pneumonia



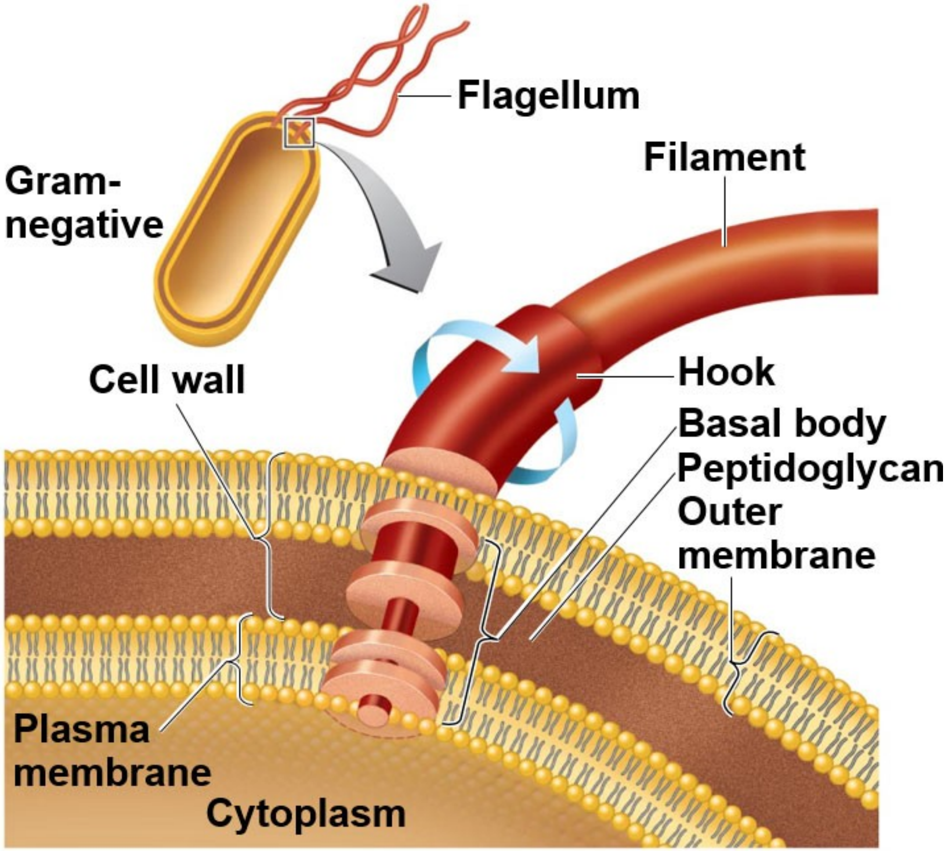
Flagella (1 of 3)

- Filamentous appendages external of the cell
- Propel bacteria
- Made of protein flagellin

Flagella (2 of 3)

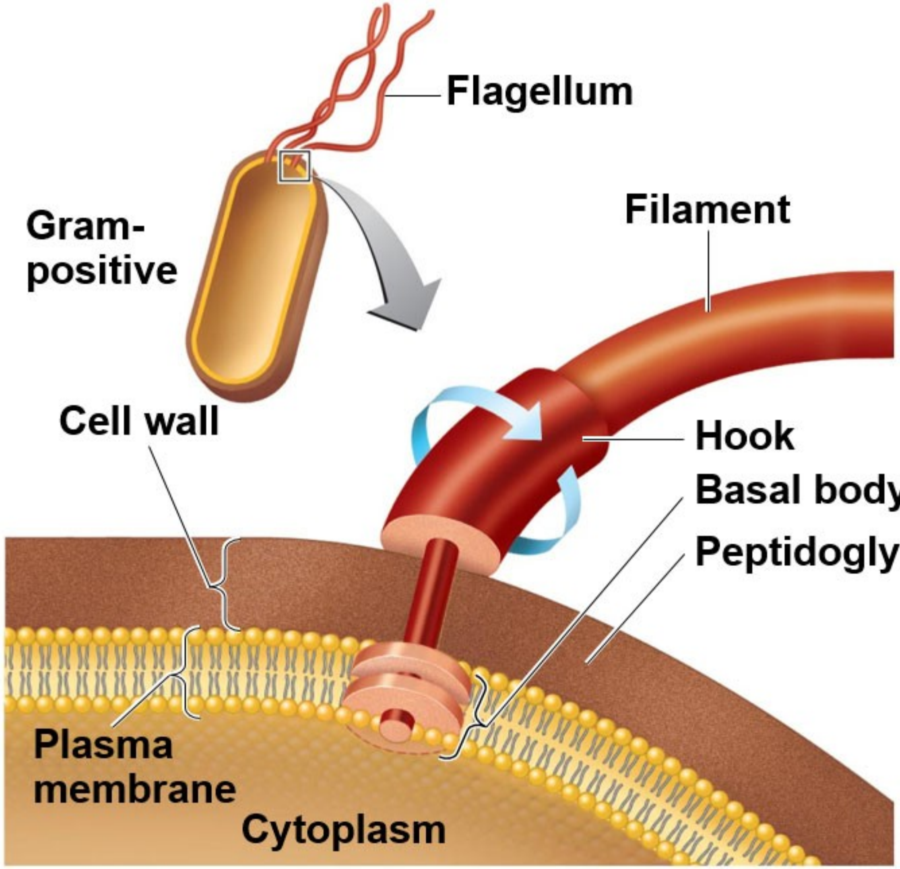
- Three parts:
  - Filament: outermost region
  - Hook: attaches to the filament
  - Basal body: consists of rod and pairs of rings; anchors flagellum to the cell wall and membrane

Figure 4.8a The Structure of a Prokaryotic Flagellum



(a) Parts and attachment of a flagellum of a gram-negative bacterium

Figure 4.8b The Structure of a Prokaryotic Flagellum

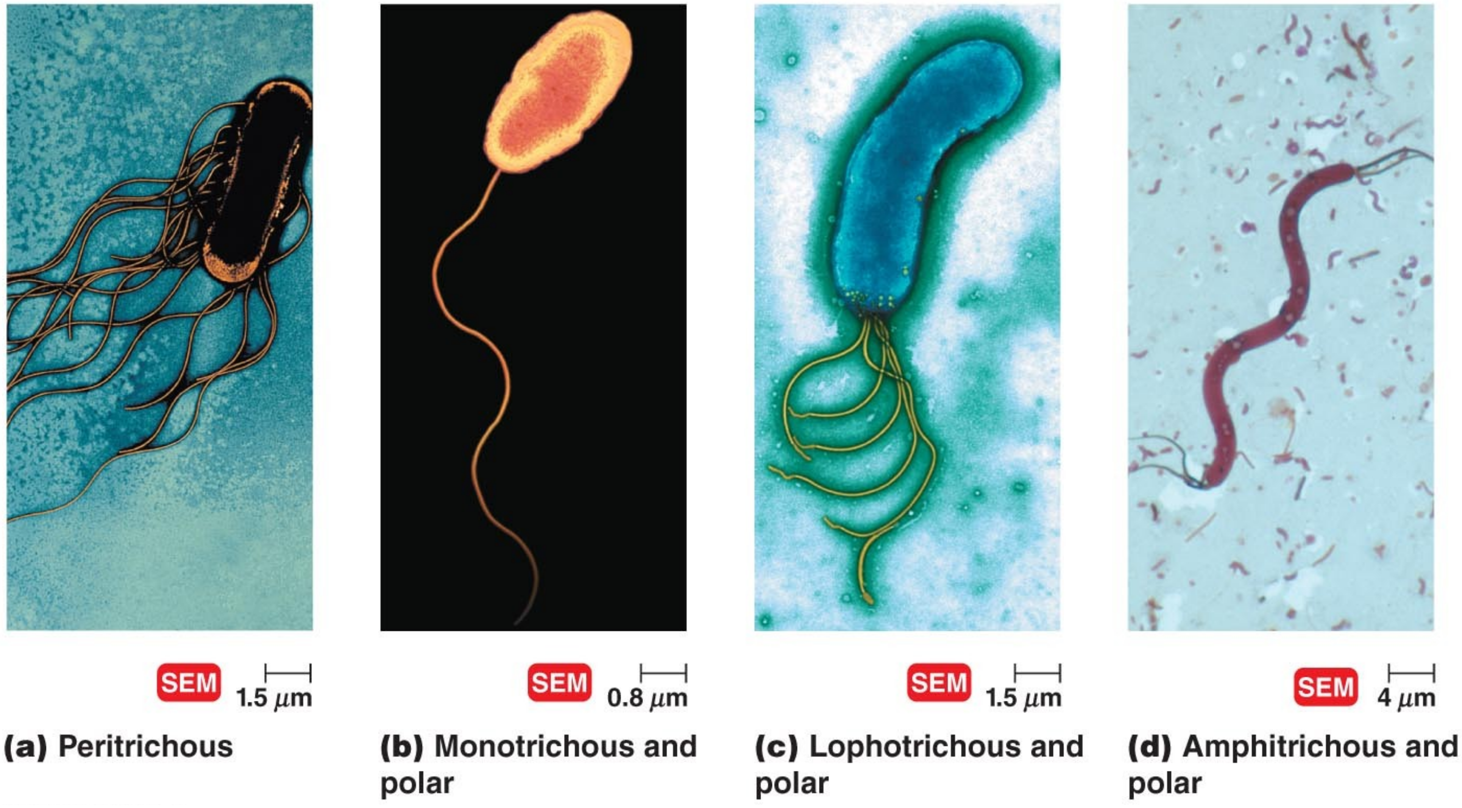


(b) Parts and attachment of a flagellum of a gram-positive bacterium

Flagella: Structure

PLAY **Animation: Flagella: Structure**

Figure 4.7 Arrangements of Bacterial Flagella



Flagella: Arrangement

PLAY **Animation: Flagella: Arrangement**

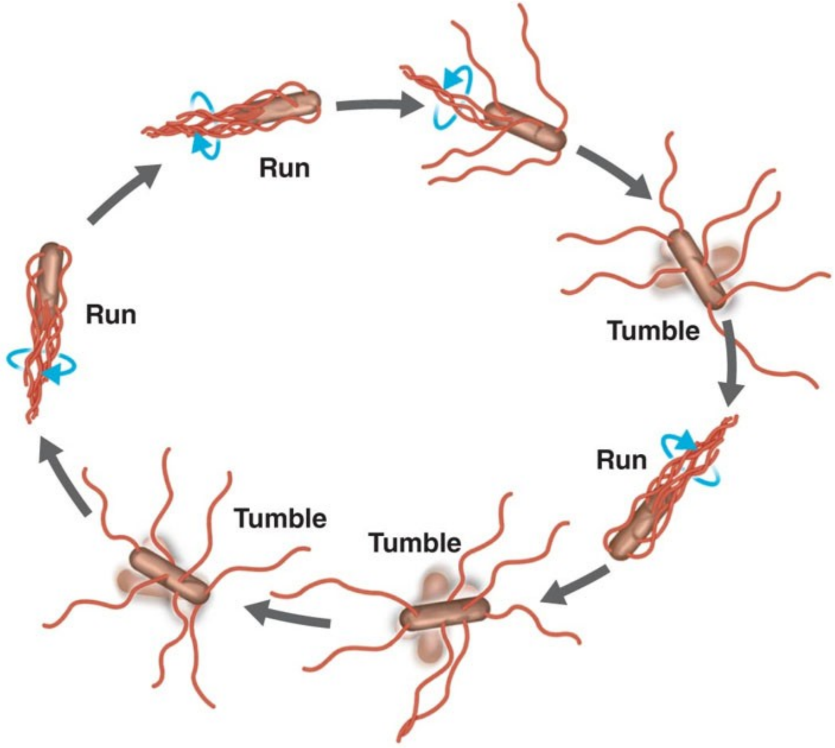
Flagella (3 of 3)

- Flagella allow bacteria to move toward or away from stimuli (**taxis**)
- Flagella rotate to "run" or "tumble"
- Flagella proteins are H antigens and distinguish among **serovars** (e.g., **Escherichia coli** O157:H7)

Motility

PLAY **Animation: Motility**

Figure 4.9a Flagella and Bacterial Motility

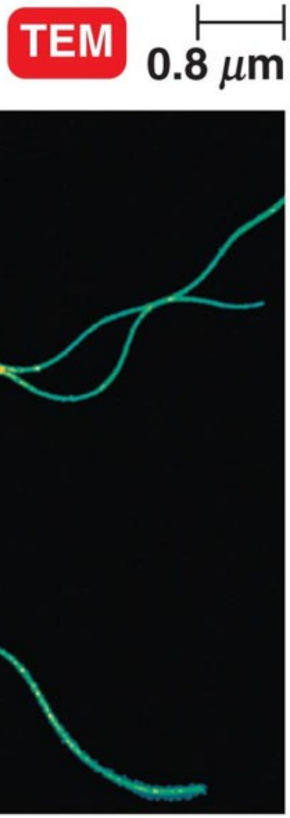


(a) A bacterium running and tumbling. Notice that the direction of flagellar rotation (blue arrows) determines which of these movements occurs. Gray arrows indicate direction of movement of the microbe.

Flagella: Movement

PLAY **Animation: Flagella: Movement**

Figure 4.9b Flagella and Bacterial Motility

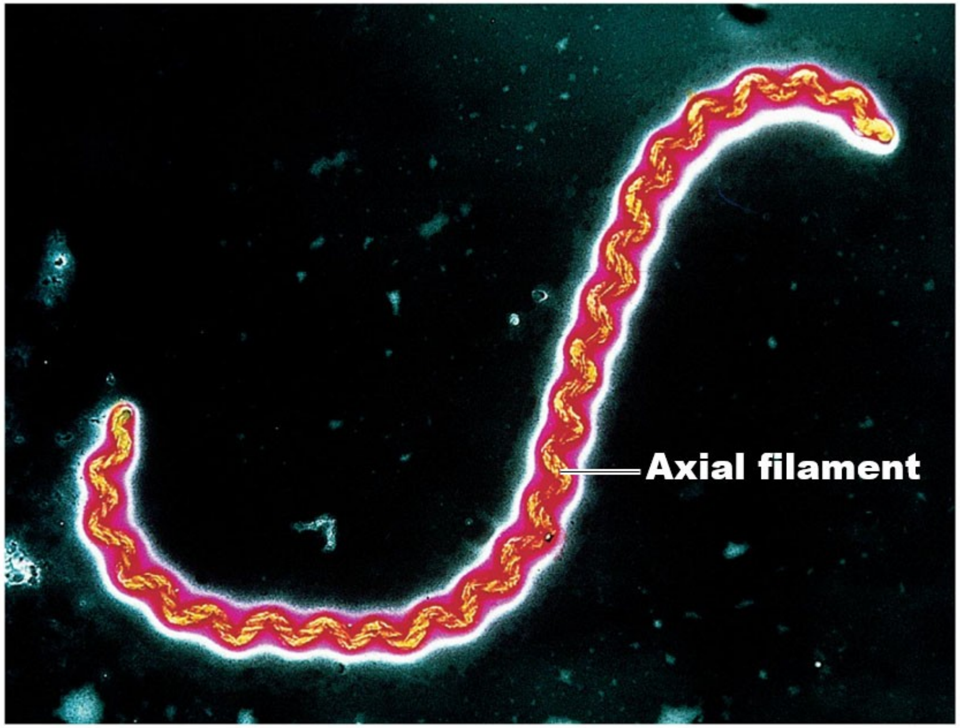


(b) A Proteus cell in the swarming stage may have more than 1000 peritrichous flagella.

Axial Filaments

- Also called **endoflagella**
- Found in spirochetes
- Anchored at one end of a cell
- Rotation causes cell to move like a corkscrew

Figure 4.10a Axial Filaments

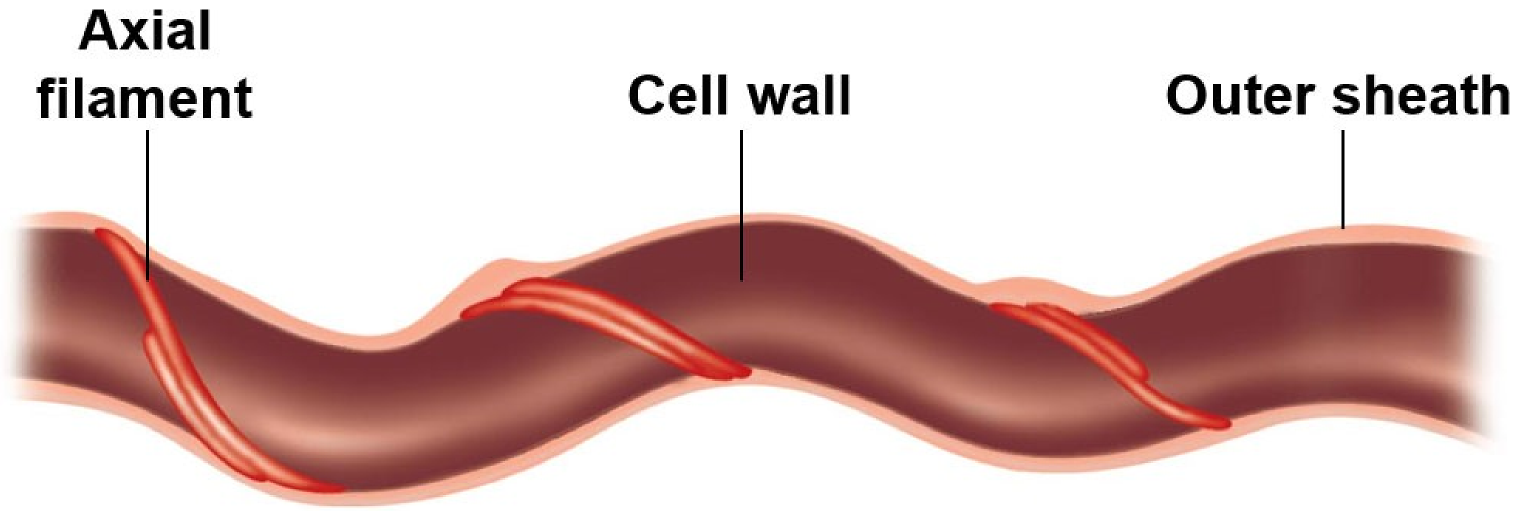


(a) A photomicrograph of the spirochete **Leptospira**, showing an axial filament

Spirochetes

PLAY **Animation: Spirochetes**

Figure 4.10b Axial Filaments



(b) A diagram of axial filaments wrapping around part of a spirochete

Fimbriae and Pili (1 of 2)

- **Fimbriae**
  - Hairlike appendages that allow for attachment

Figure 4.11 Fimbriae

Fimbriae and Pili (2 of 2)

- **Pili**
  - Involved in motility (**gliding** and **twitching** motility)
  - **Conjugation pili** involved in DNA transfer from one cell to another

Check Your Understanding-3

Check Your Understanding

- ✓ Why are bacterial capsules medically important
  4-3
- ✓ How do bacteria move?
  4-4

The Cell Wall (1 of 2)

Learning Objectives

4-5 Compare and contrast the cell walls of gram-positive bacteria, gram-negative bacteria, acid-fast bacteria, archaea, and mycoplasmas.

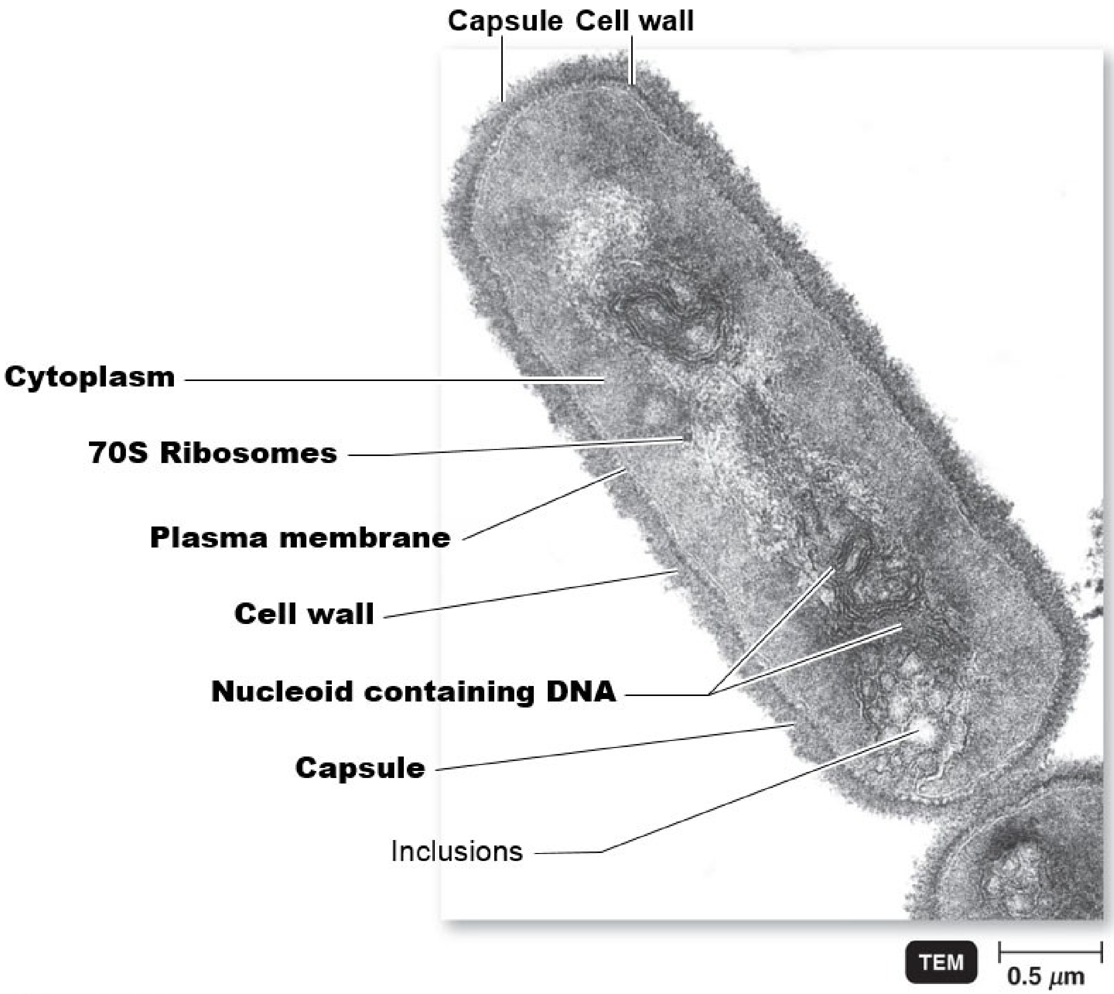
4-6 Compare and contrast archaea and mycoplasmas.

4-7 Differentiate **protoplast, spheroplast,** and *L* **form.**

The Cell Wall (2 of 2)

- Prevents osmotic lysis and protects the cell membrane
- Made of **peptidoglycan** (in bacteria)
- Contributes to pathogenicity

Figure 4.6 The Structure of a Prokaryotic Cell (2 of 2)



Composition and Characteristics

- Peptidoglycan
  - Polymer of a repeating disaccharide in rows:
    - N-acetylglucosamine (NAG)
    - N-acetylmuramic acid (NAM)
- Rows are linked by polypeptides

Figure 4.12 N-acetylglucosamine (NAG) and N-acetylmuramic Acid (NAM)

N-acetylglucosamine (NAG) and N-acetylmuramic acid (NAM) joined as in a peptidoglycan.

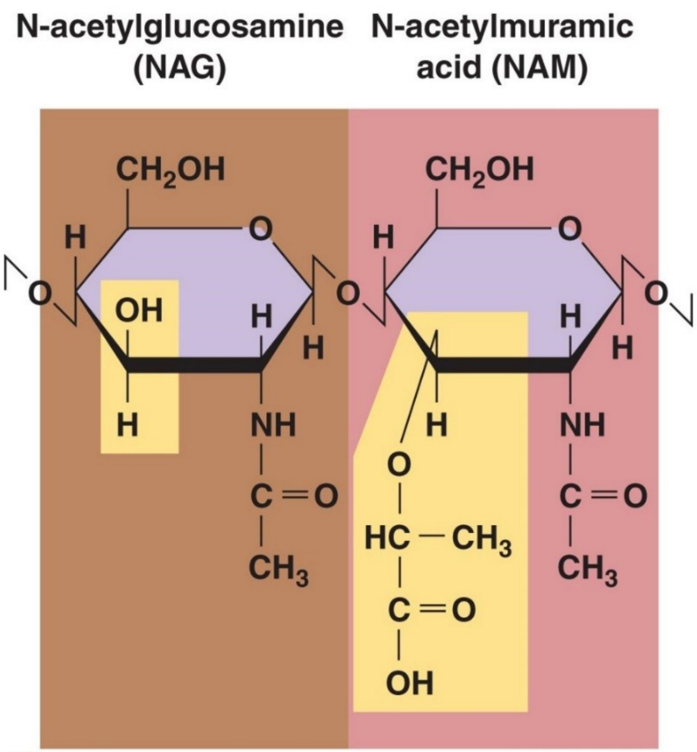
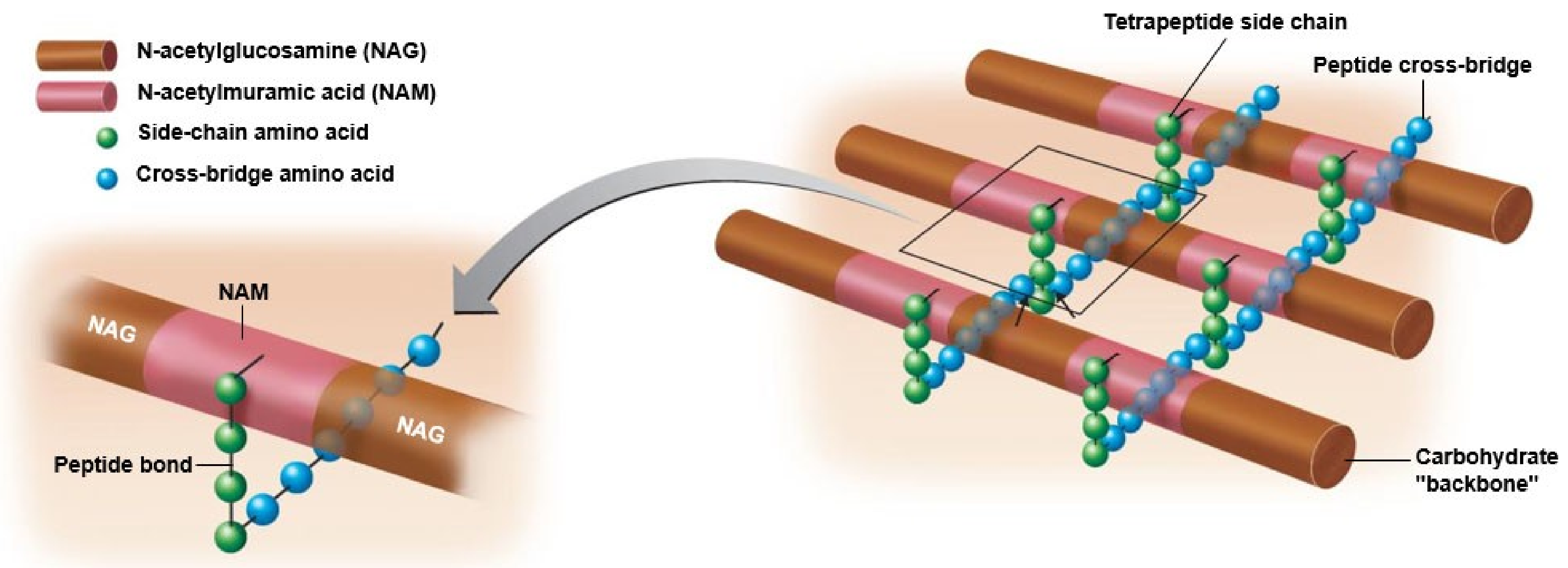


Figure 4.13a Bacterial Cell Walls



(a) Structure of peptidoglycan in gram-positive bacteria

Gram-Positive Cell Walls (1 of 3)

- Thick peptidoglycan
- Teichoic acids

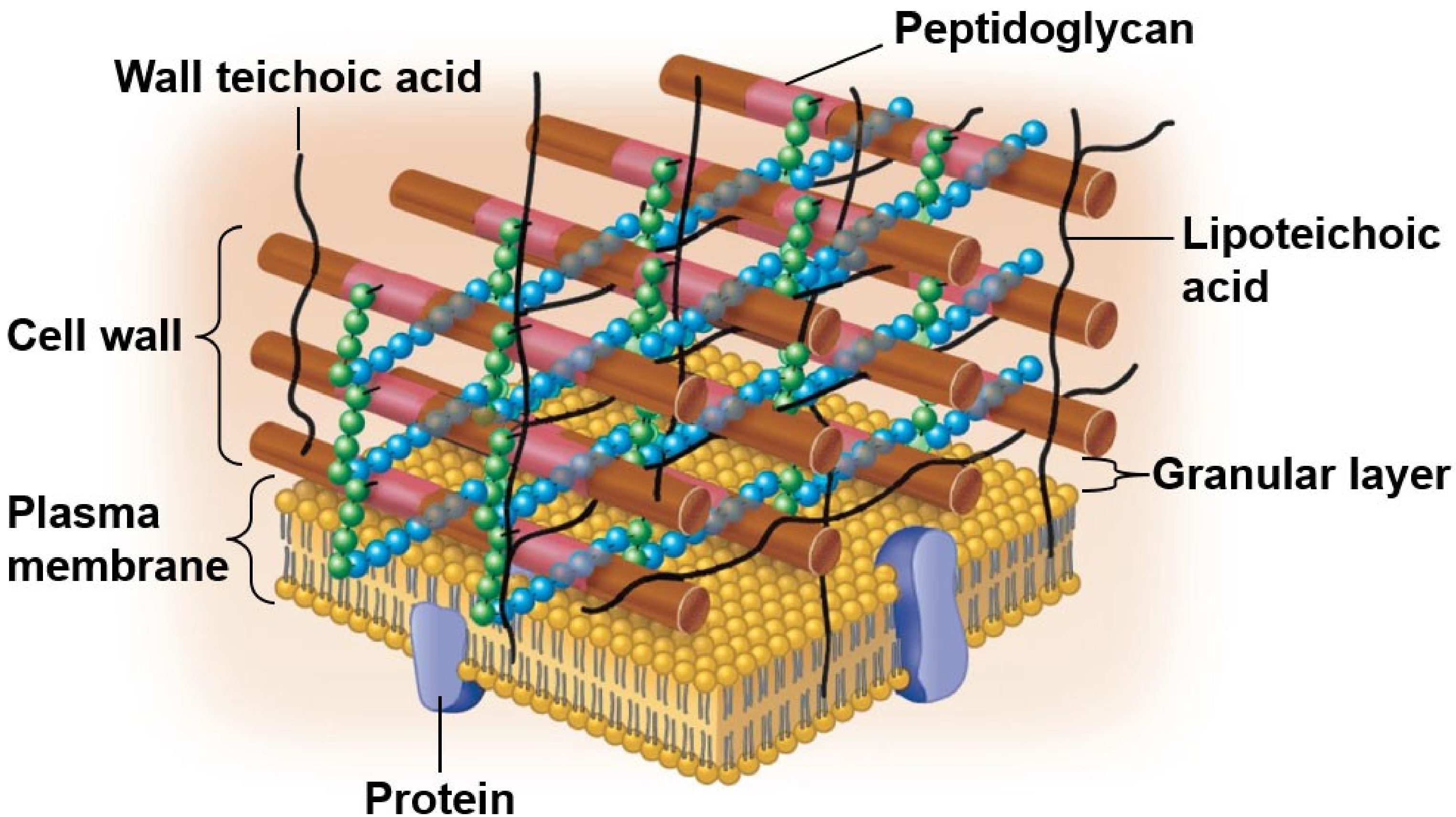
Gram-Negative Cell Walls (1 of 4)

- Thin peptidoglycan
- Outer membrane
- Periplasmic space

Gram-Positive Cell Walls (2 of 3)

- Teichoic acids
  - Lipoteichoic acid links cell wall to plasma membrane
  - Wall teichoic acid links the peptidoglycan
  - Carry a negative charge
  - Regulate movement of cations
- Polysaccharides and teichoic acids provide antigenic specificity

Figure 4.13b Bacterial Cell Walls



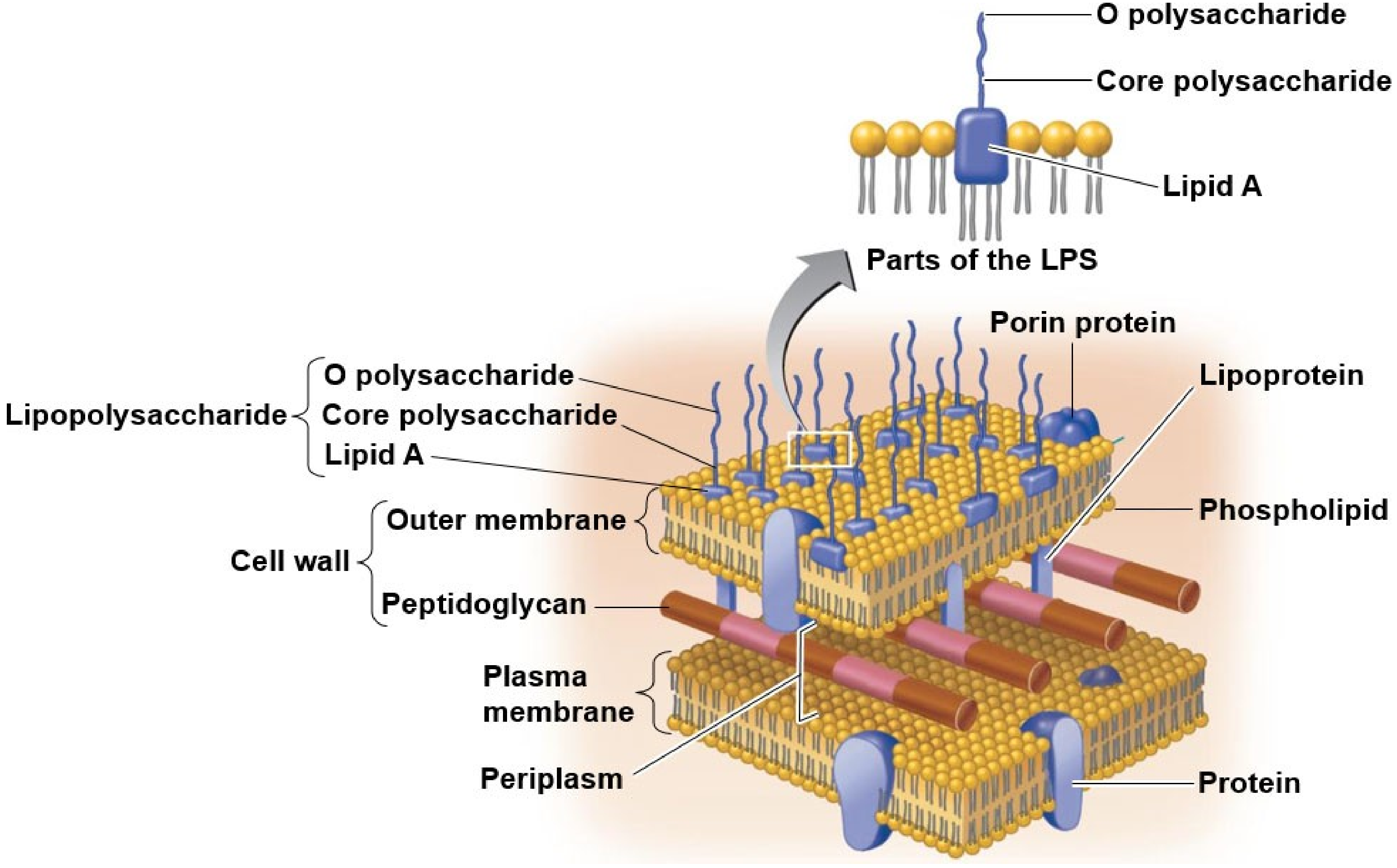
Gram-Negative Cell Walls (2 of 4)

- Periplasm between the outer membrane and the plasma membrane contains peptidoglycan
- Outer membrane made of polysaccharides, lipoproteins, and phospholipids

Gram-Negative Cell Walls (3 of 4)

- Protect from phagocytes, complement, and antibiotics
- Made of **lipopolysaccharide (LPS)**
  - **O polysaccharide** functions as antigen (e.g., **E.coli** O157:H7)
  - **Lipid A** is an endotoxin embedded in the top layer
- **Porins** (proteins) form channels through membrane

Figure 4.13c Bacterial Cell Walls



Cell Walls and the Gram Stain Mechanism

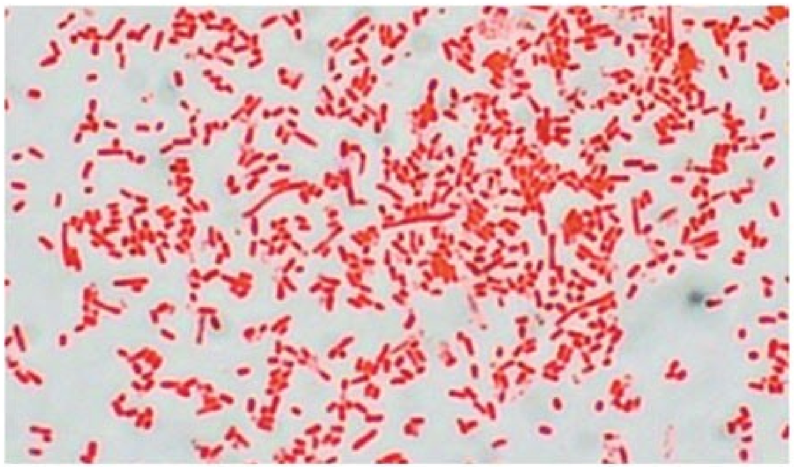
- Crystal violet-iodine crystals form inside cell
- Gram-positive
  - Alcohol dehydrates peptidoglycan
  - CV-I crystals do not leave
- Gram-negative
  - Alcohol dissolves outer membrane and leaves holes in peptidoglycan
  - CV-I washes out; cells are colorless
  - Safranin added to stain cells

Table 4.1 Some Comparative Characteristics of Gram-Positive and Gram-Negative Bacteria

Gram-Positive

LM 12 µm

Gram-Negative



LM 15 µm

Gram-Positive Cell Walls (3 of 3)

- 2-rings in basal body of flagella
- Produce exotoxins
- High susceptibility to penicillin
- Disrupted by lysozyme

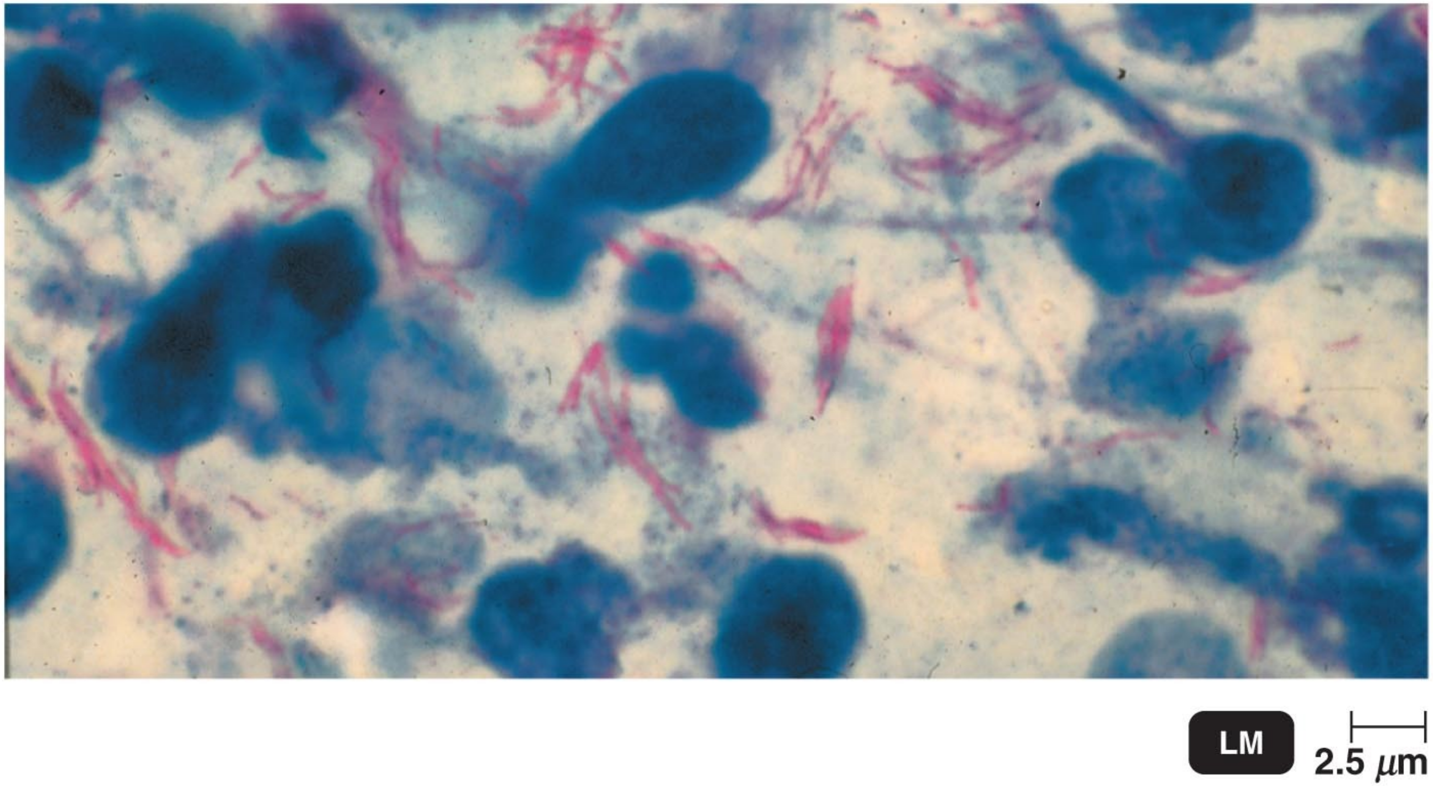
Gram-Negative Cell Walls (4 of 4)

- 4-rings in basal body of flagella
- Produce endotoxins and exotoxins
- Low susceptibility to penicillin

Atypical Cell Walls (1 of 2)

- Acid-fast cell walls
  - Like gram-positive cell walls
  - Waxy lipid (**mycolic acid**) bound to peptidoglycan
  - ***Mycobacterium***
  - ***Nocardia***
  - Stain with carbolfuchsin

Figure 24.7 Mycobacterium Tuberculosis



Atypical Cell Walls (2 of 2)

- Mycoplasmas
  - Lack cell walls
  - Sterols in plasma membrane
- Archaea
  - Wall-less, or
  - Walls of pseudomurein (lack NAM and D-amino acids)

Damage to the Cell Wall (1 of 2)

- Lysozyme hydrolyzes bonds in peptidoglycan
- Penicillin inhibits peptide bridges in peptidoglycan
- **Protoplast** is a wall-less gram-positive cell
- **Spheroplast** is a wall-less gram-negative cell
  - Protoplasts and spheroplasts are susceptible to osmotic lysis
- **L forms** are wall-less cells that swell into irregular shapes

Check Your Understanding-4

Check Your Understanding

- ✓ Why are drugs that target cell wall synthesis useful?

  4-5

- ✓ Why are mycoplasmas resistant to antibiotics that interfere with cell wall synthesis?

  4-6

- ✓ How do protoplasts differ from L forms?

  4-7

Structures Internal to the Cell Wall

Learning Objectives

4-8 Describe the structure, chemistry, and functions of the prokaryotic plasma membrane.

4-9 Define **simple diffusion, facilitated diffusion, osmosis, active transport,** and **group translocation.**

4-10 Identify the functions of the nucleoid and ribosomes.

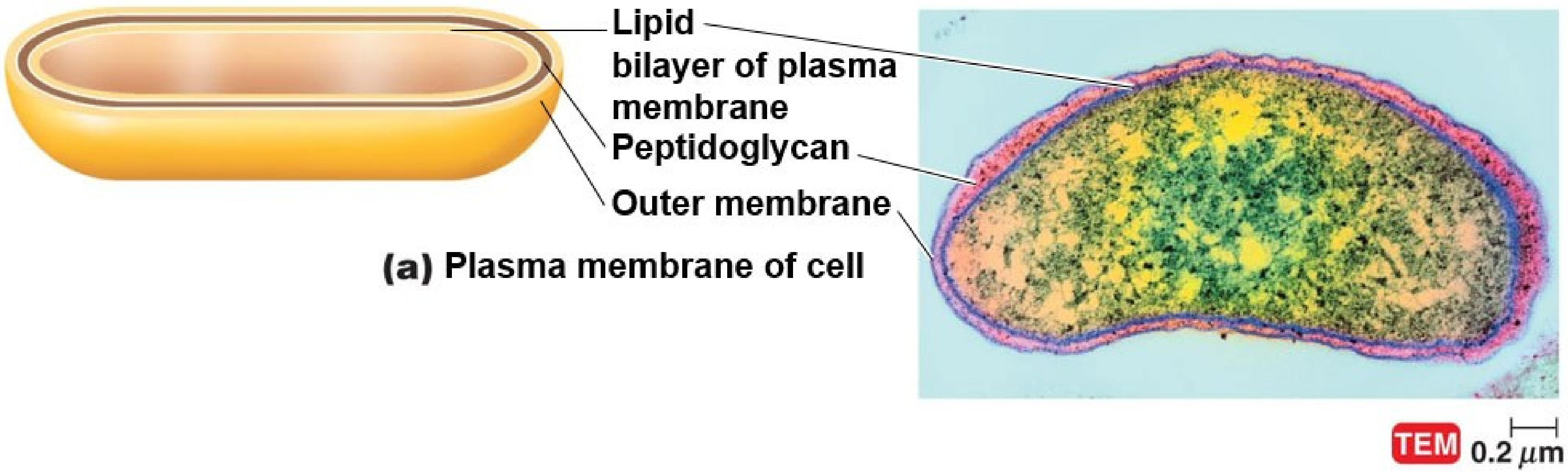
4-11 Identify the functions of four inclusions.

4-12 Describe the functions of endospores, sporulation, and endospore germination.

The Plasma (Cytoplasmic) Membrane

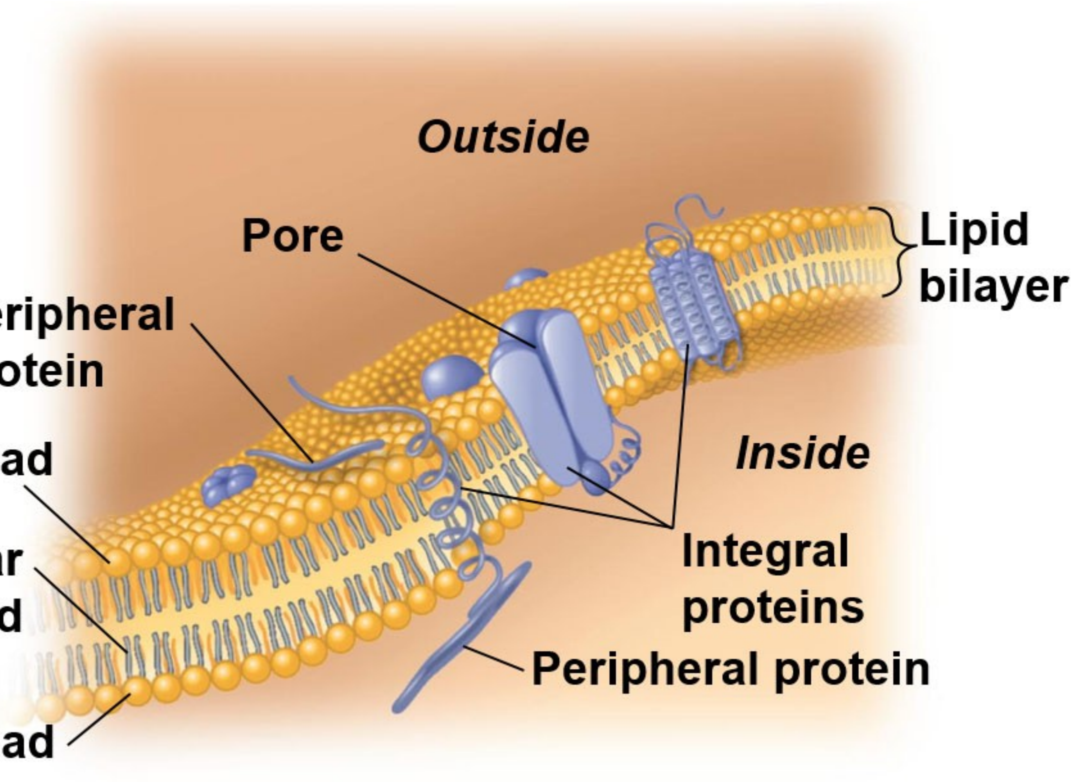
- Phospholipid bilayer that encloses the cytoplasm
- Peripheral proteins on the membrane surface
- Integral and transmembrane proteins penetrate the membrane

Figure 4.14a Plasma Membrane



(a) Plasma membrane of cell

Figure 4.14b Plasma Membrane



(b) Lipid bilayer of plasma membrane

Membrane Structure

PLAY **Animation: Membrane Structure**

Structure

- **Fluid mosaic model**
  - Membrane is as viscous as olive oil
  - Proteins move freely for various functions
  - Phospholipids rotate and move laterally
  - Self-sealing

Functions (1 of 2)

- The plasma membrane's **selective permeability** allows the passage of some molecules, but not others
- Contain enzymes for ATP production
- Some membranes have photosynthetic pigments on foldings called **chromatophores**

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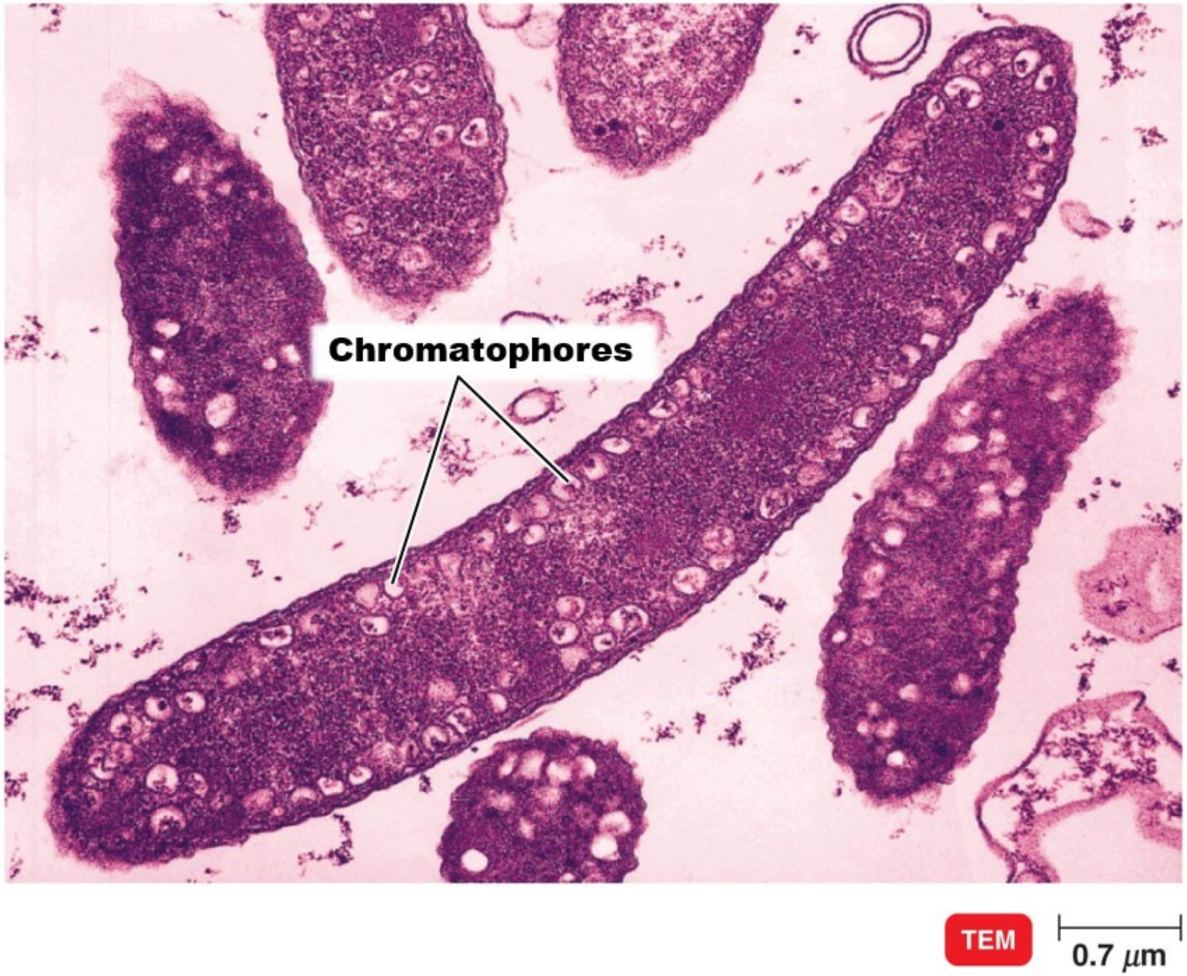
Membrane Permeability

PLAY **Animation: Membrane Permeability**

Figure 4.15 Chromatophores



Functions (2 of 2)

- Damage to the membrane by alcohols, quaternary ammonium (detergents), and polymyxin antibiotics causes leakage of cell contents

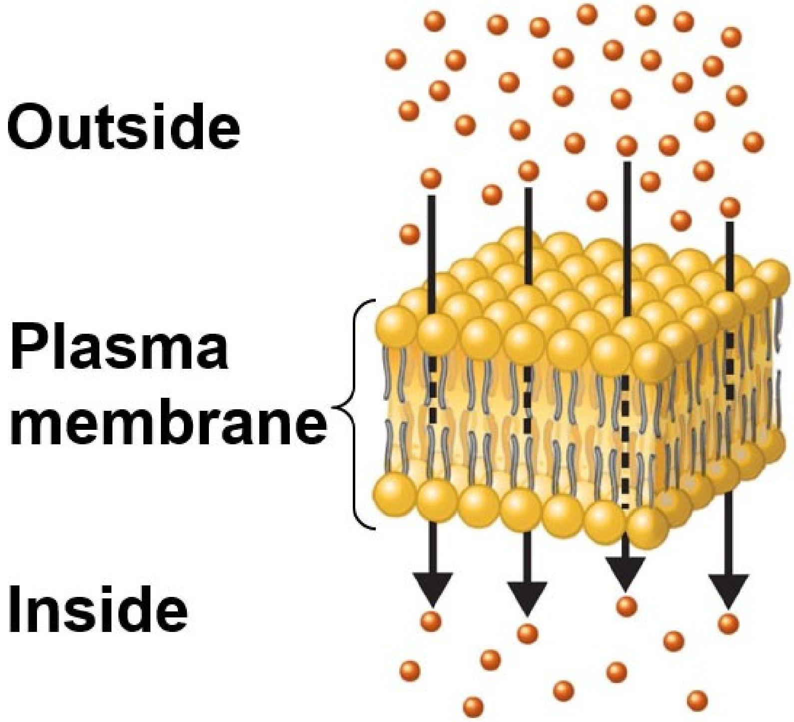
The Movement of Materials Across Membranes

- Passive processes: substances move from high concentration to low concentration; no energy expended
- Active processes: substances move from low concentration to high concentration; energy expended

Passive Processes (1 of 5)

- **Simple diffusion:** movement of a solute from an area of high concentration to an area of low concentration
- Continues until molecules reach equilibrium

Figure 4.17a Passive Processes



(a) Simple diffusion through the lipid bilayer

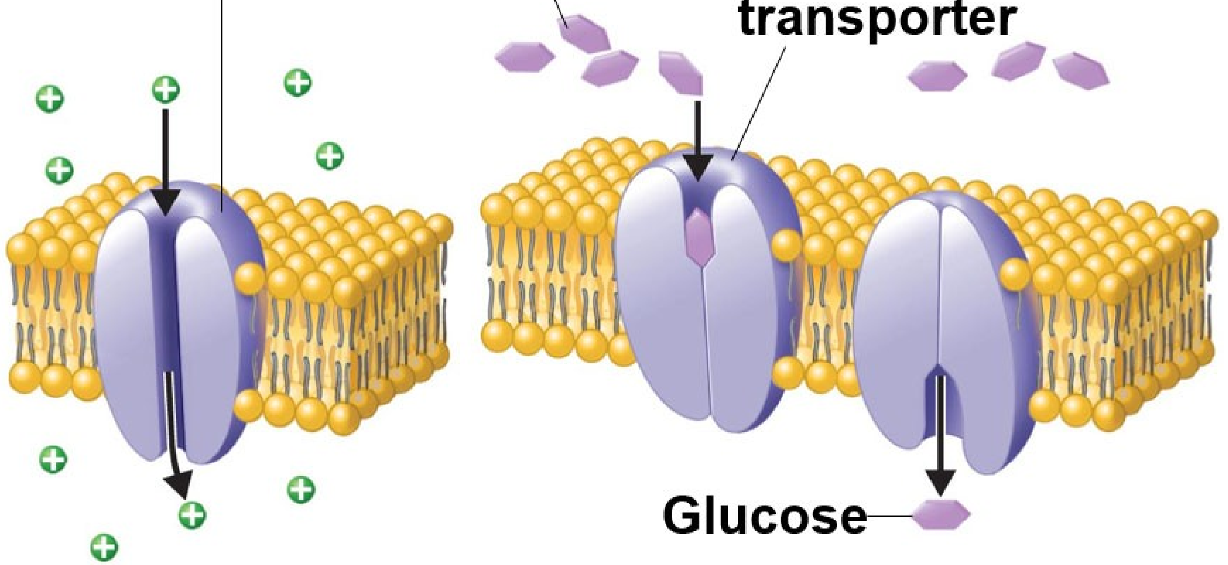
Passive Transport: Principles of Diffusion

PLAY **Animation: Passive Transport: Principles of Diffusion**

Passive Processes (2 of 5)

- **Facilitated diffusion:** solute combines with a transporter protein in the membrane
- Transports ions and larger molecules across a membrane with the concentration gradient

Figure 4.17b-c Passive Processes



(b) Facilitated diffusion through a nonspecific transporter

(c) Facilitated diffusion through a specific transporter

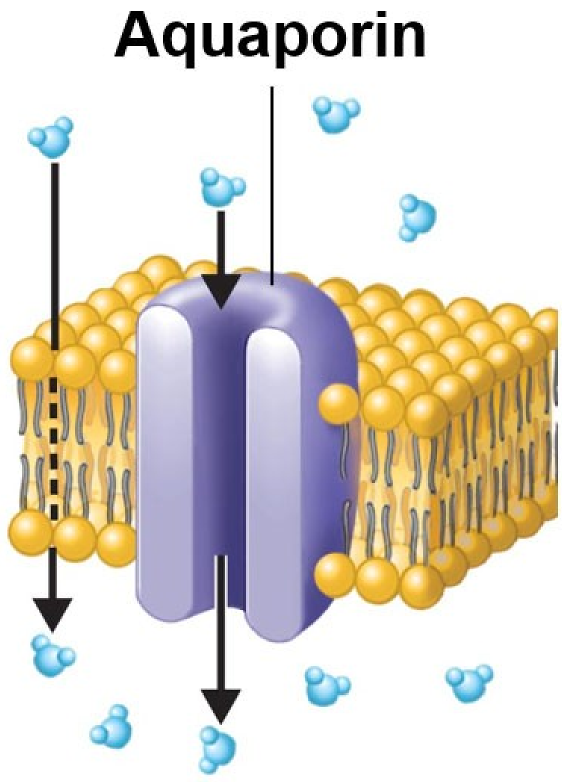
Passive Transport: Special Types of Diffusion

PLAY **Animation: Passive Transport: Special Types of Diffusion**

Passive Processes (3 of 5)

- **Osmosis:** the movement of water across a selectively permeable membrane from an area of high water to an area of lower water concentration
- Through lipid layer
- Aquaporins (water channels)

Figure 4.17d Passive Processes

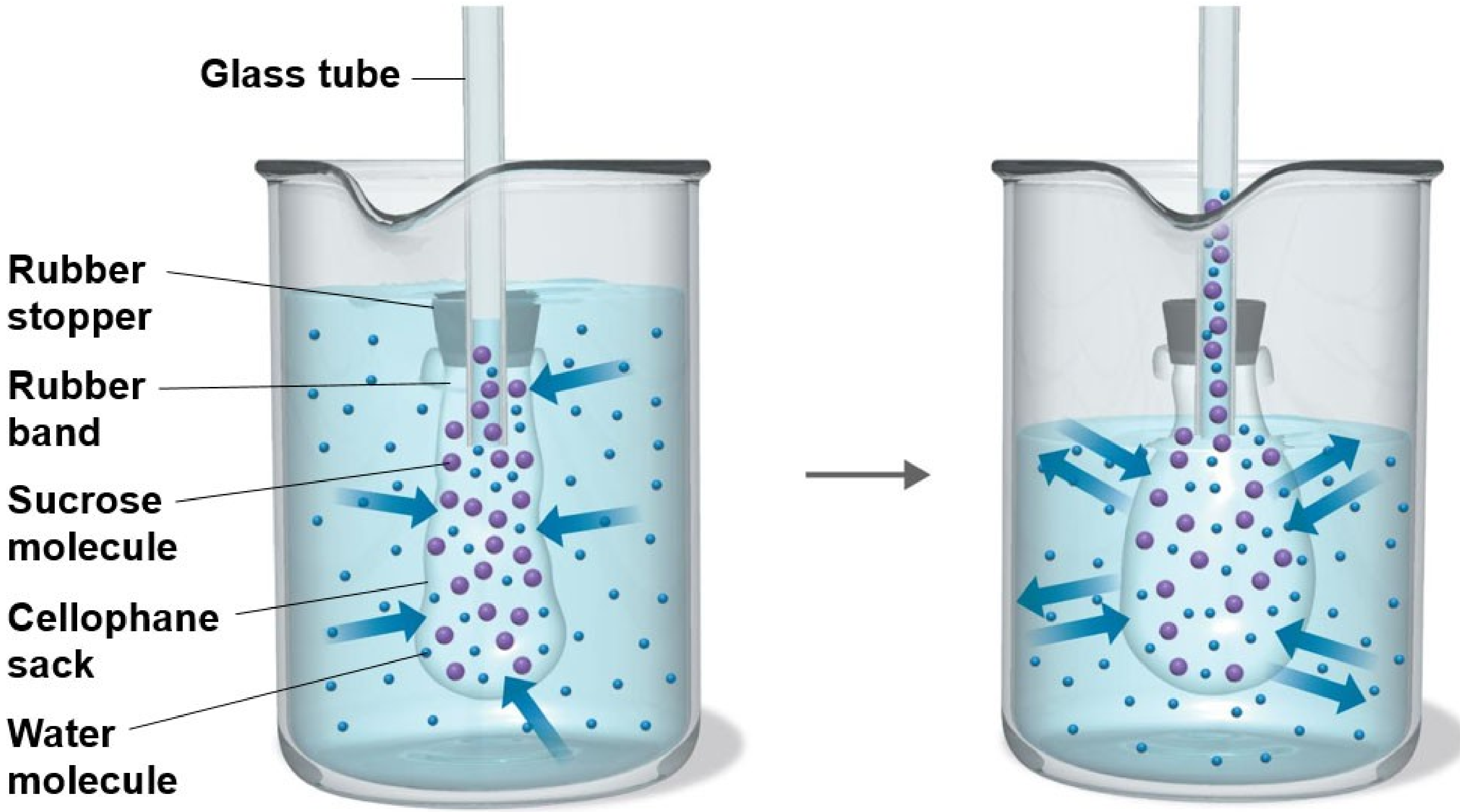


(d) Osmosis through the lipid bilayer (left) and an aquaporin (right)

Passive Processes (4 of 5)

- **Osmotic pressure:** the pressure needed to stop the movement of water across the membrane

Figure 4.18a-b The Principle of Osmosis



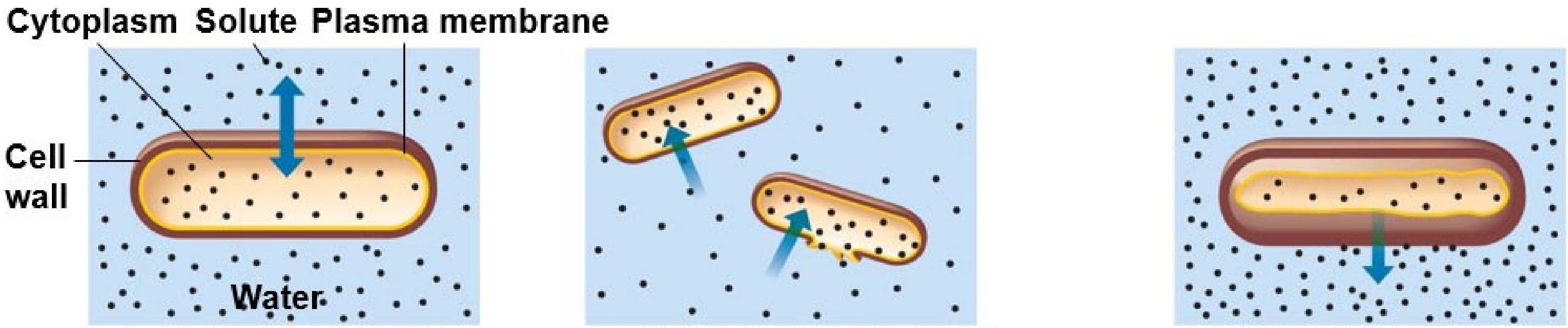
(a) At beginning of osmotic pressure experiment

(b) At equilibrium

Passive Processes (5 of 5)

- **Isotonic solution:** solute concentrations equal inside and outside of cell; water is at equilibrium
- **Hypotonic solution:** solute concentration is lower outside than inside the cell; water moves into cell
- **Hypertonic solution:** solute concentration is higher outside of cell than inside; water moves out of cell

Figure 4.18c-e The Principle of Osmosis



(c) Isotonic solution. No net movement of water occurs.

(d) Hypotonic solution. Water moves into the cell. If the cell wall is strong, it contains the swelling. If the cell wall is weak or damaged, the cell bursts (osmotic lysis).

(e) Hypertonic solution. Water moves out of the cell, causing its cytoplasm to shrink (plasmolysis).

Active Processes

- **Active transport:** requires a transporter protein and ATP; goes against gradient
- **Group translocation:** requires a transporter protein and phosphoenolpyruvic acid (PEP); substance is altered as it crosses the membrane

Active Transport: Overview

PLAY **Animation: Active Transport: Overview**

Active Transport: Types

PLAY **Animation: Active Transport: Types**

Check Your Understanding-5

Check Your Understanding

- ✓ Which agents can cause injury to the bacterial plasma membrane?
  4-8
- ✓ How are simple diffusion and facilitated diffusion similar? How are they different?
  4-9

Cytoplasm

- The substance inside the plasma membrane
- Eighty percent water plus proteins, carbohydrates, lipids, and ions
- Cytoskeleton

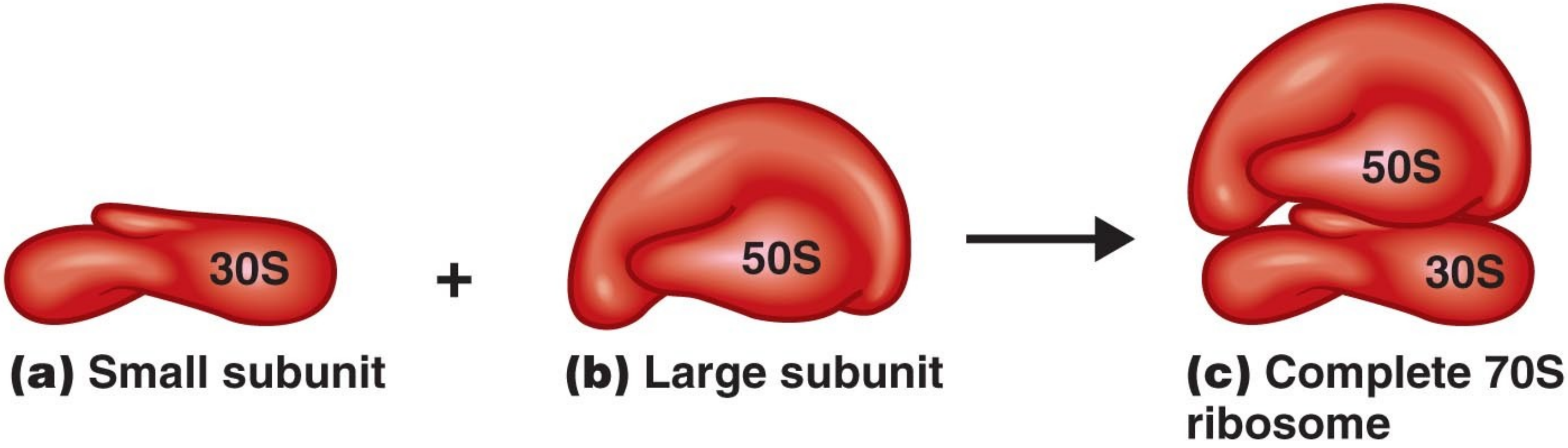
The Nucleoid

- **Bacterial chromosome:** circular thread of DNA that contains the cell's genetic information
- **Plasmids:** extrachromosomal genetic elements; carry non-crucial genes (e.g., antibiotic resistance, production of toxins)

Ribosomes

- Sites of protein synthesis
- Made of protein and ribosomal RNA
- 70S
  - 50S + 30S subunits

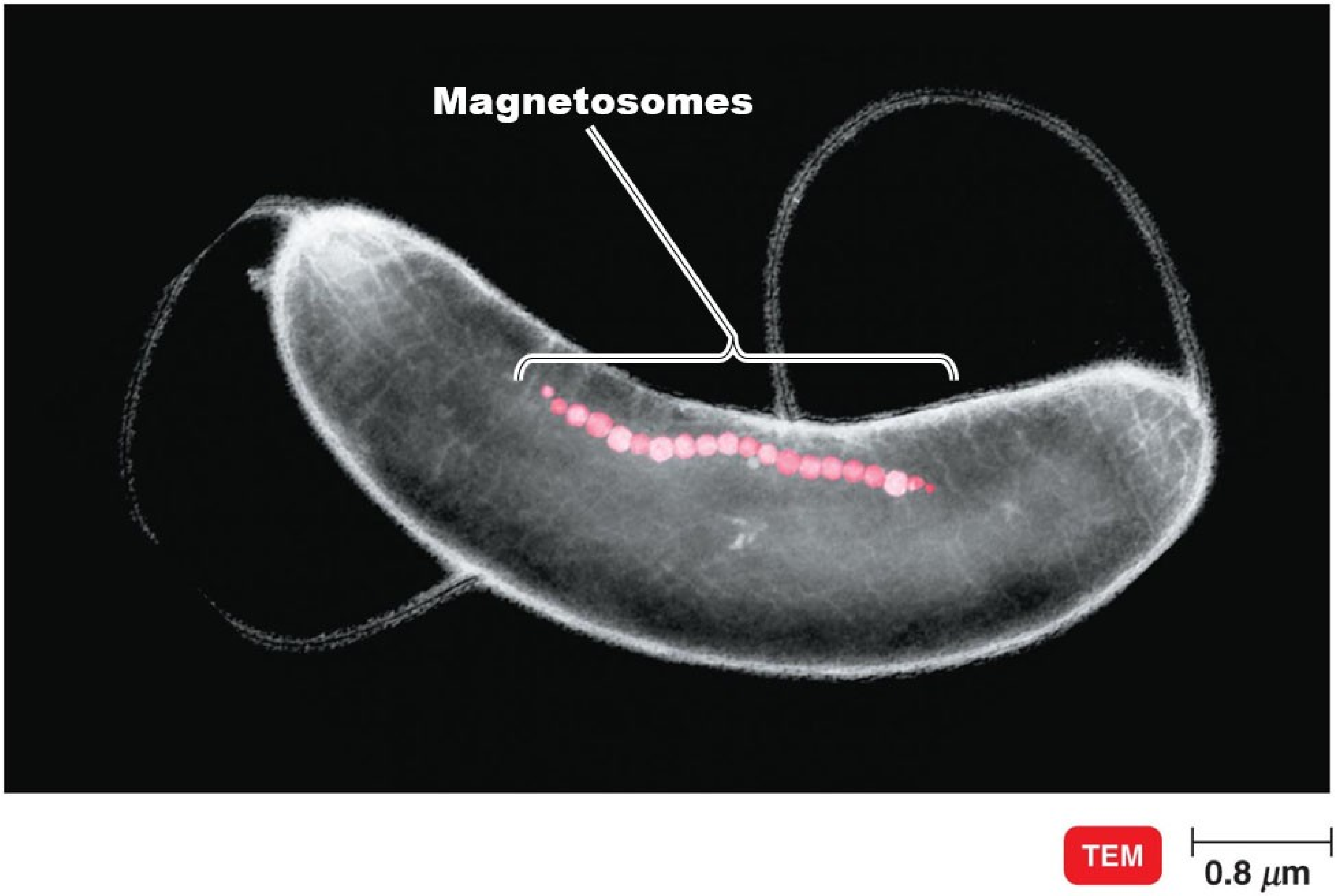
Figure 4.19 The Prokaryotic Ribosome



Inclusions

- **Metachromatic granules (volutin)**—phosphate reserves
- **Polysaccharide granules**—energy reserves
- **Lipid inclusions**—energy reserves
- **Sulfur granules**—energy reserves
- **Carboxysomes**—RuBisCO enzyme for CO_2 fixation during photosynthesis
- **Gas vacuoles**—protein-covered cylinders that maintain buoyancy
- **Magnetosomes**—iron oxide inclusions; destroy H_2O_2

Figure 4.20 Magnetosomes



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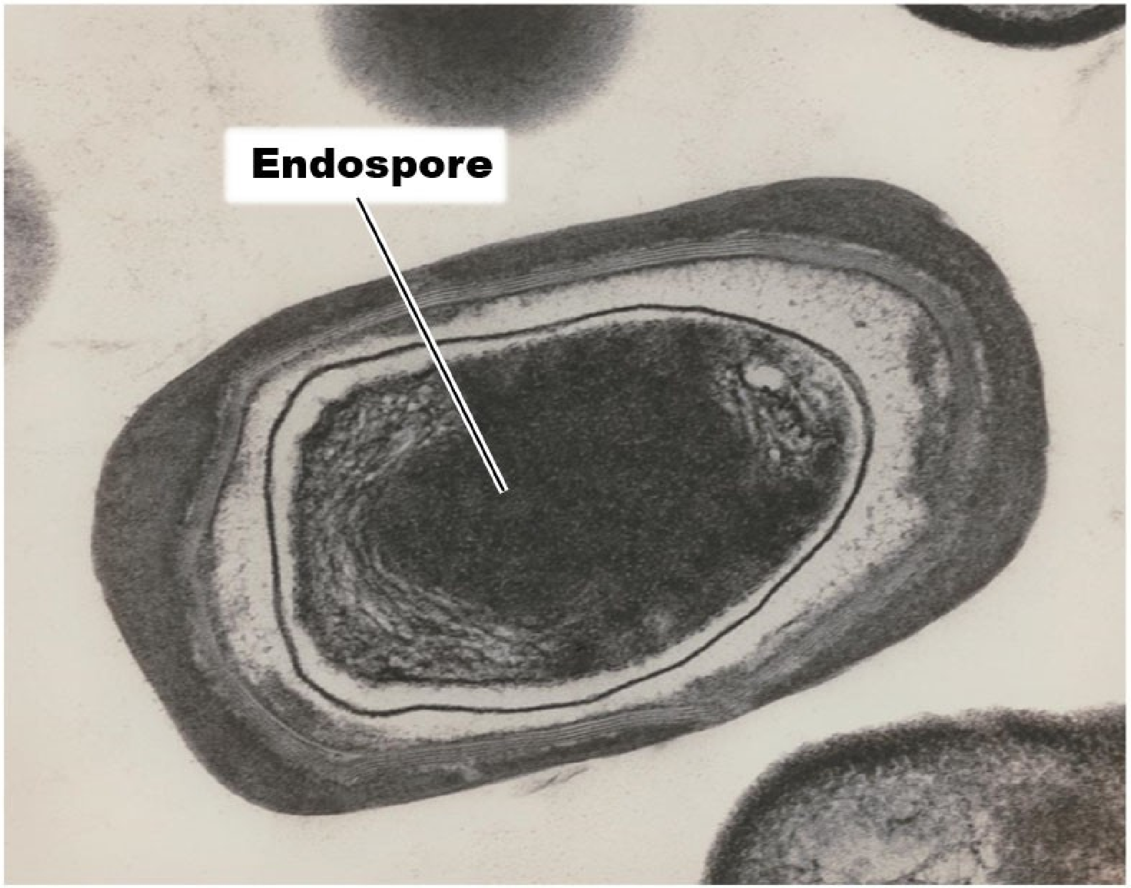
Endospores

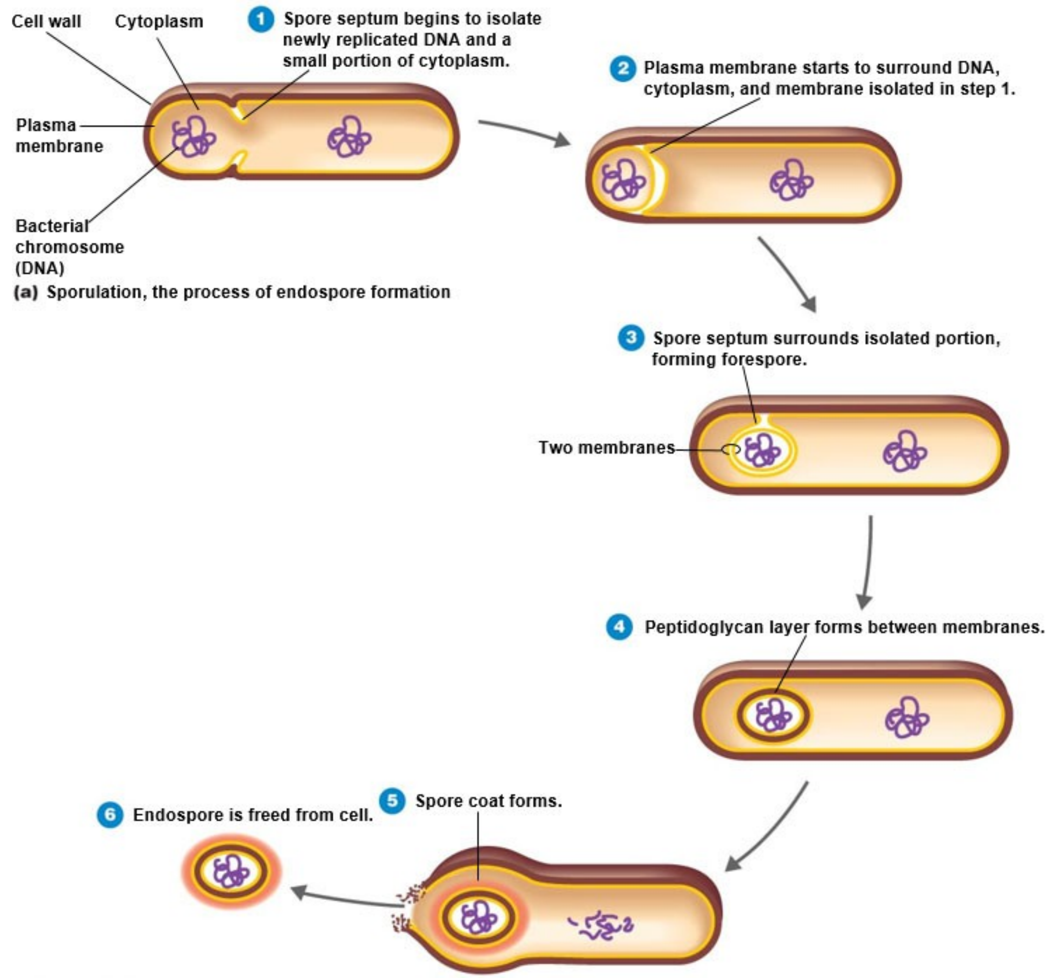
- Resting cells; produced when nutrients are depleted
- Resistant to desiccation, heat, chemicals, and radiation
- Produced by **Bacillus** and **Clostridium**
- **Sporulation:** endospore formation
- **Germination:** endospore returns to vegetative state

Figure 4.21b Formation of Endospores by Sporulation



(b) An endospore of Bacillus subtilis

Figure 4.21a Formation of Endospores by Sporulation



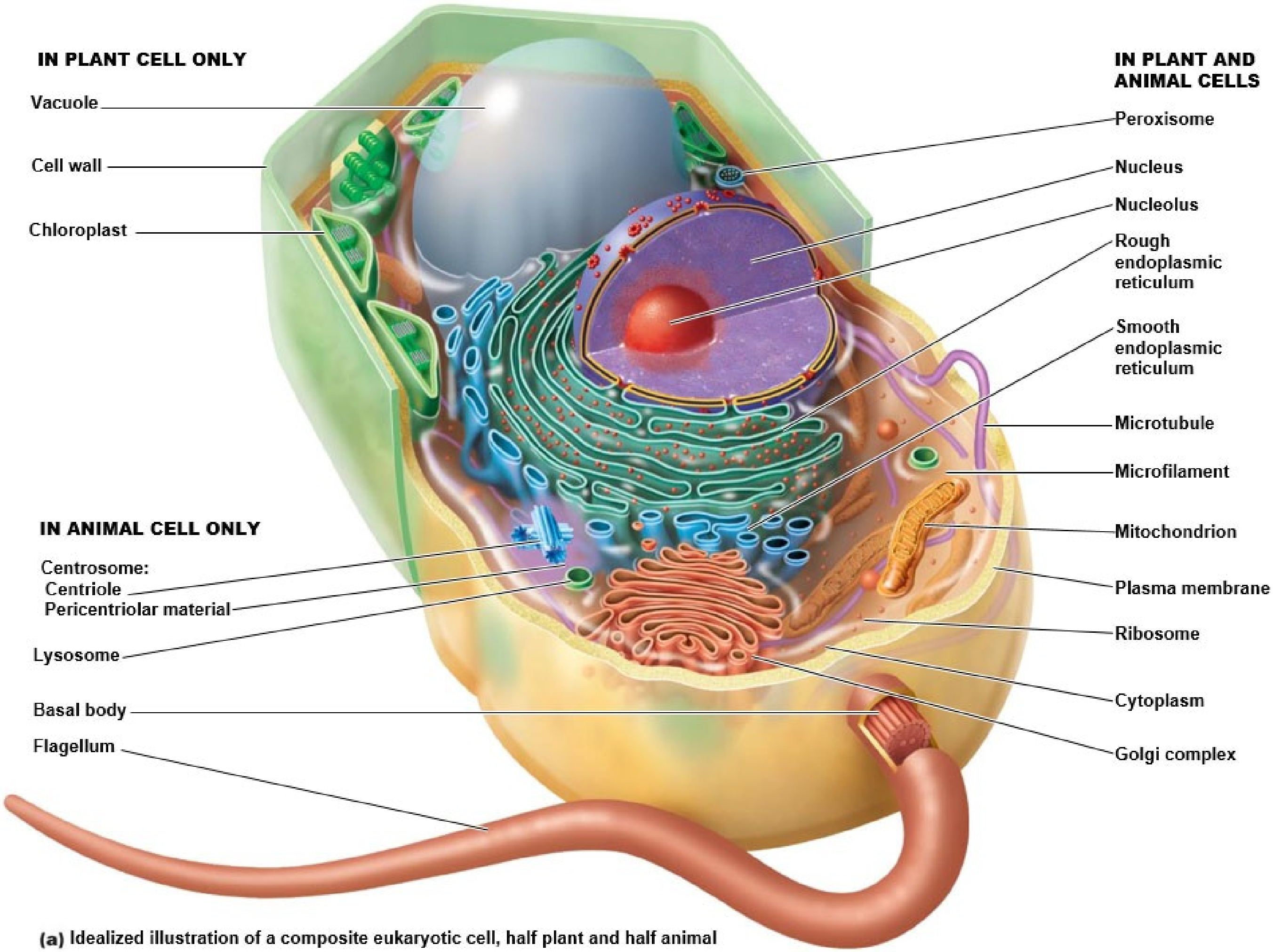
(a) Sporulation, the process of endospore formation

Check Your Understanding-6

Check Your Understanding

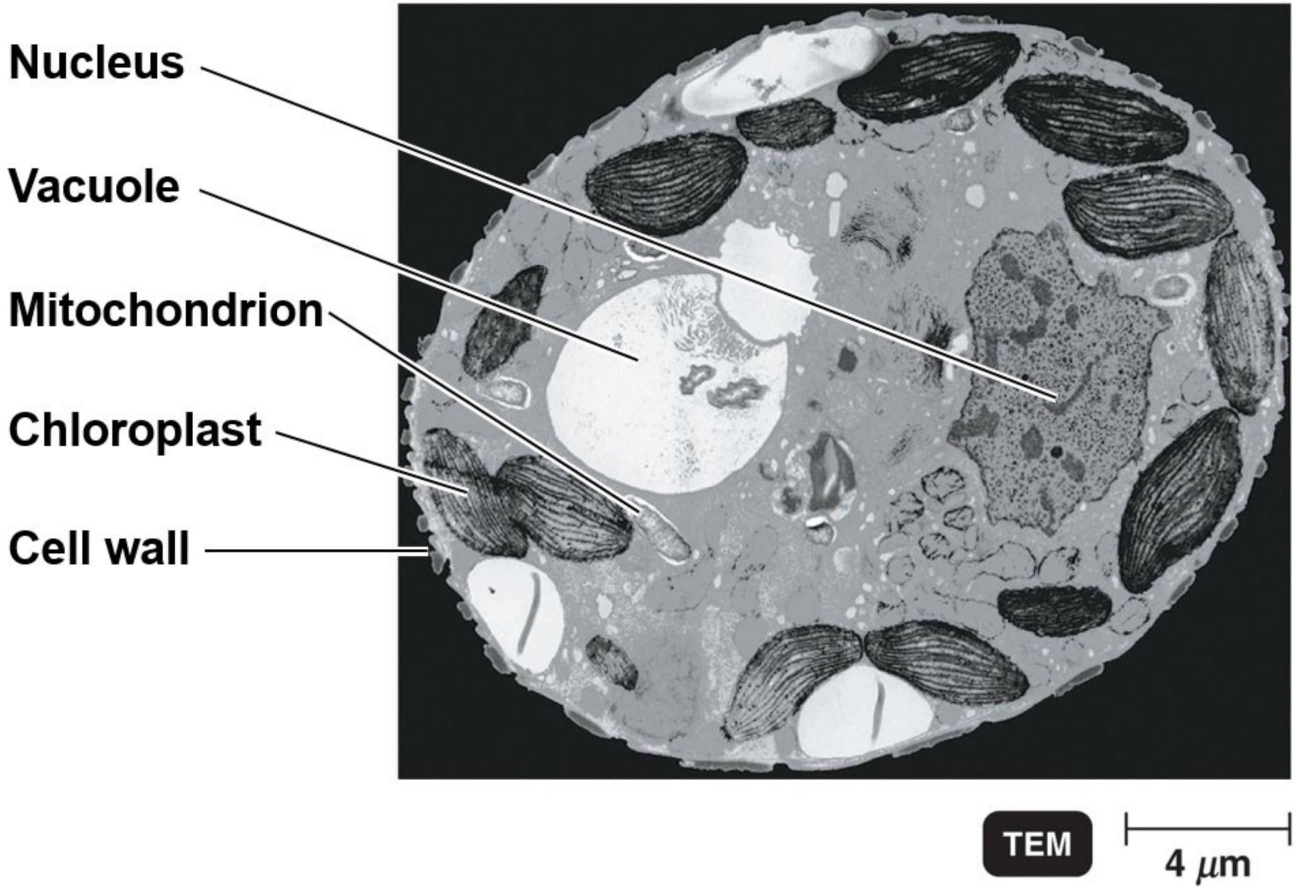
- ✓ Where is the DNA located in a prokaryotic cell 4-10
- ✓ What is the general function of inclusions? 4-11
- ✓ Under what conditions do endospores form? 4-12

Figure 4.22a Eukaryotic Cells Showing Typical Structures



(a) Idealized illustration of a composite eukaryotic cell, half plant and half animal

Figure 4.22b Eukaryotic Cells Showing Typical Structures



(b) Transmission electron micrograph of plant cell

Pearson

Flagella and Cilia (1 of 3)

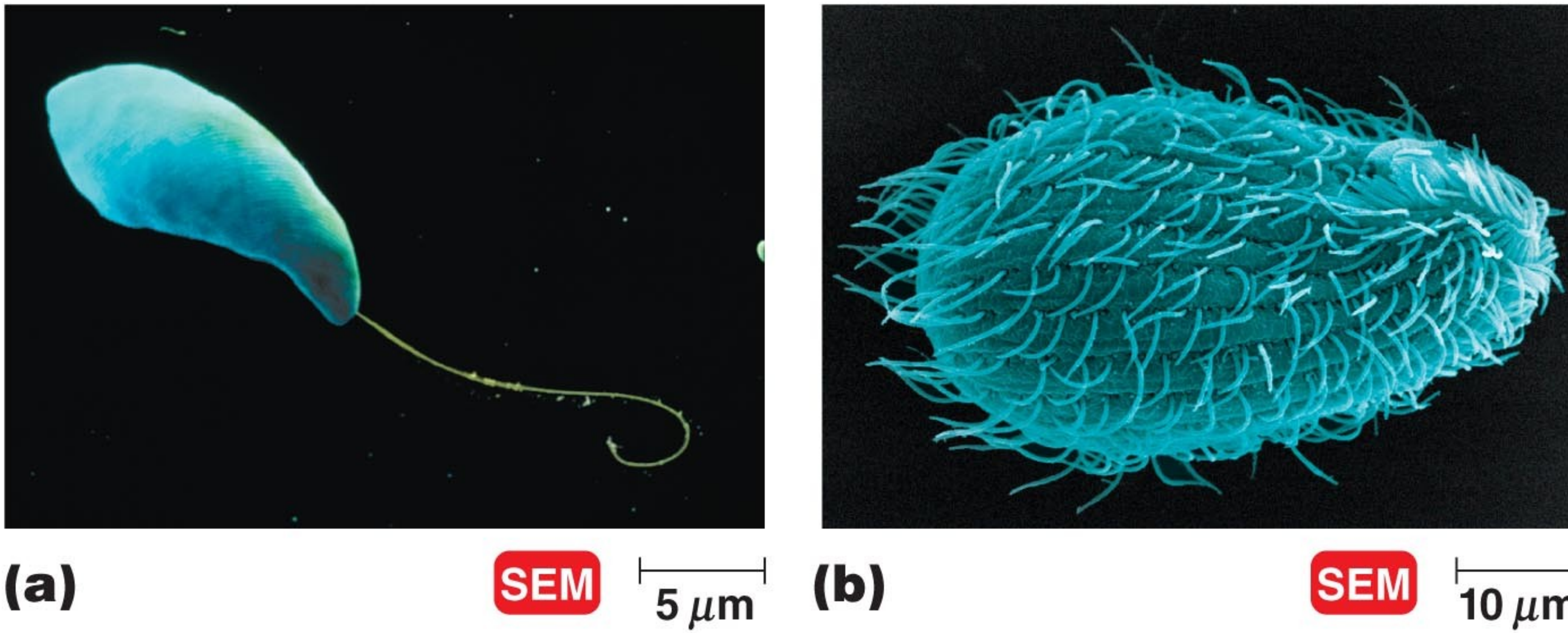
Learning Objective

4-13 Differentiate prokaryotic and eukaryotic flagella.

Flagella and Cilia (2 of 3)

- Projections used for locomotion or moving substances along the cell surface
- **Flagella**—long projections; few in number
- **Cilia**—short projections; numerous

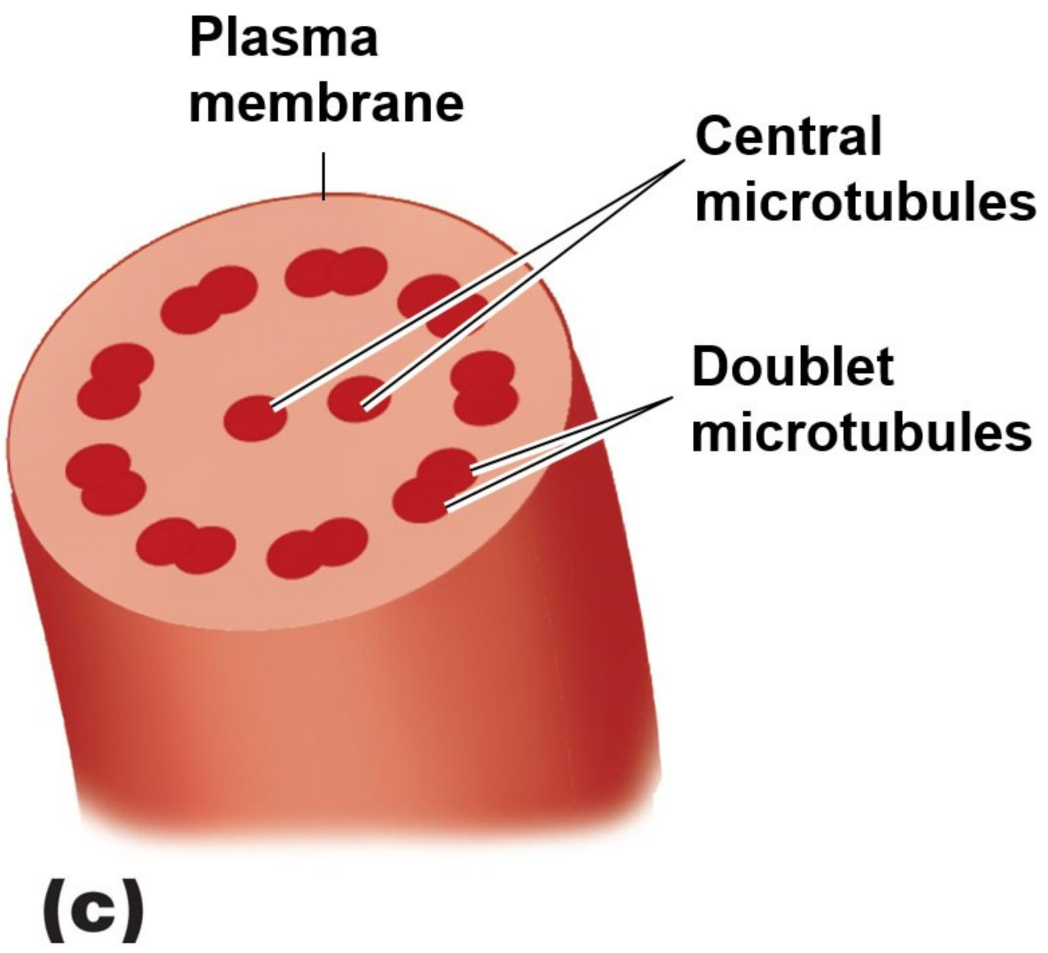
Figure 4.23a-b Eukaryotic Flagella and Cilia



Flagella and Cilia (3 of 3)

- Both consist of **microtubules** made of the protein **tubulin**
- Microtubules are organized as nine pairs in a ring, plus two microtubules in the center (9 + 2 array)
- Allow flagella to move in a wavelike manner

Figure 4.23c Eukaryotic Flagella and Cilia



The Cell Wall and Glycocalyx (1 of 2)

Learning Objective

4-14 Compare and contrast prokaryotic and eukaryotic cell walls and glycocalyxes.

The Cell Wall and Glycocalyx (2 of 2)

- Cell wall
  - Found in plants, algae, and fungi
  - Made of carbohydrates (cellulose—plants, chitin—fungi, glucan and mannan—yeasts)
- **Glycocalyx**
  - Carbohydrates bonded to proteins and lipids in the plasma membrane
  - Found in animal cells

The Plasma (Cytoplasmic) Membrane (1 of 3)

Learning Objective

4-15 Compare and contrast prokaryotic and eukaryotic plasma membranes.

The Plasma (Cytoplasmic) Membrane (2 of 3)

- Similar in structure to prokaryotic cell membranes
  - Phospholipid bilayer
  - Integral and peripheral proteins
- Differences in structure
  - Sterols—complex lipids
  - Carbohydrates—for attachment and cell-to-cell recognition

The Plasma (Cytoplasmic) Membrane (3 of 3)

- Similar in function to prokaryotic cell membranes
  - Selective permeability
  - Simple diffusion, facilitated diffusion, osmosis, active transport
- Differences in function
  - **Endocytosis**—phagocytosis and pinocytosis
  - Phagocytosis: pseudopods extend and engulf particles
  - Pinocytosis: membrane folds inward, bringing in fluid and dissolved substances

Cytoplasm (1 of 2)

Learning Objective

4-16 Compare and contrast prokaryotic and eukaryotic cytoplasms.

Cytoplasm (2 of 2)

- **Cytoplasm:** substance inside the plasma and outside the nucleus
- **Cytosol:** fluid portion of cytoplasm
- **Cytoskeleton:** made of microfilaments and intermediate filaments; gives shape and support
- **Cytoplasmic streaming:** movement of the cytoplasm throughout a cell

Ribosomes (1 of 2)

Learning Objective

4-17 Compare the structure and function of eukaryotic and prokaryotic ribosomes.

Ribosomes (2 of 2)

- Sites of protein synthesis
- 80S
  - Consists of the large 60S subunit and the small 40S subunit
  - Membrane-bound: attached to endoplasmic reticulum
  - Free: in cytoplasm
- 70S
  - In chloroplasts and mitochondria

Pearson

Check Your Understanding-7

Check Your Understanding

- ✓ Identify at least one significant difference between eukaryotic and prokaryotic flagella and cilia, cell walls, plasma membranes, and cytoplasm.

  4-13–4-16

- ✓ The antibiotic erythromycin binds with the 50S portion of a ribosome. What effect does this have on a prokaryotic cell? On a eukaryotic cell?

  4-17

Organelles (1 of 3)

Learning Objectives

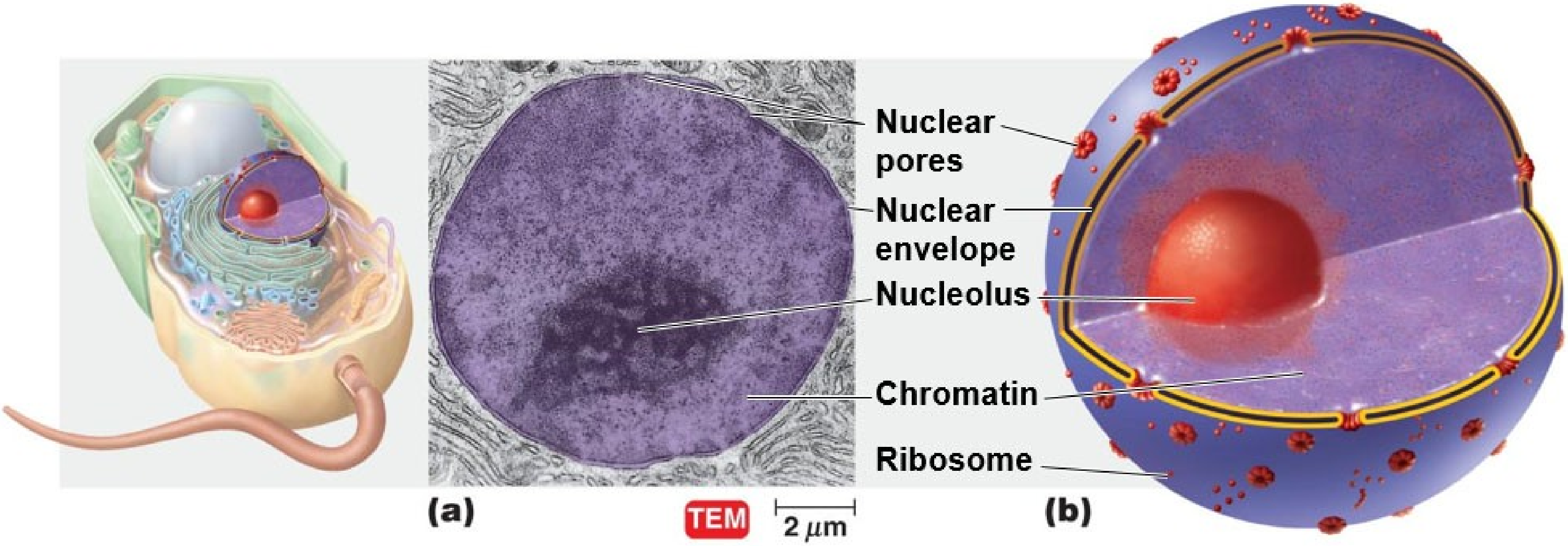
4-18 Define **organelle.**

4-19 Describe the functions of the nucleus, endoplasmic reticulum, Golgi complex, lysosomes, vacuoles, mitochondria, chloroplasts, peroxisomes, and centrosomes.

The Nucleus

- **Nucleus**
  - Double membrane structure (**nuclear envelope**) that contains the cell's DNA
  - DNA is complexed with **histone** proteins to form **chromatin**
  - During mitosis and meiosis, chromatin condenses into **chromosomes**

Figure 4.24 The Eukaryotic Nucleus



Endoplasmic Reticulum

- Folded transport network
- **Rough ER:** studded with ribosomes; sites of protein synthesis
- **Smooth ER:** no ribosomes; synthesizes cell membranes, fats, and hormones

Figure 4.25 Rough Endoplasmic Reticulum and Ribosomes

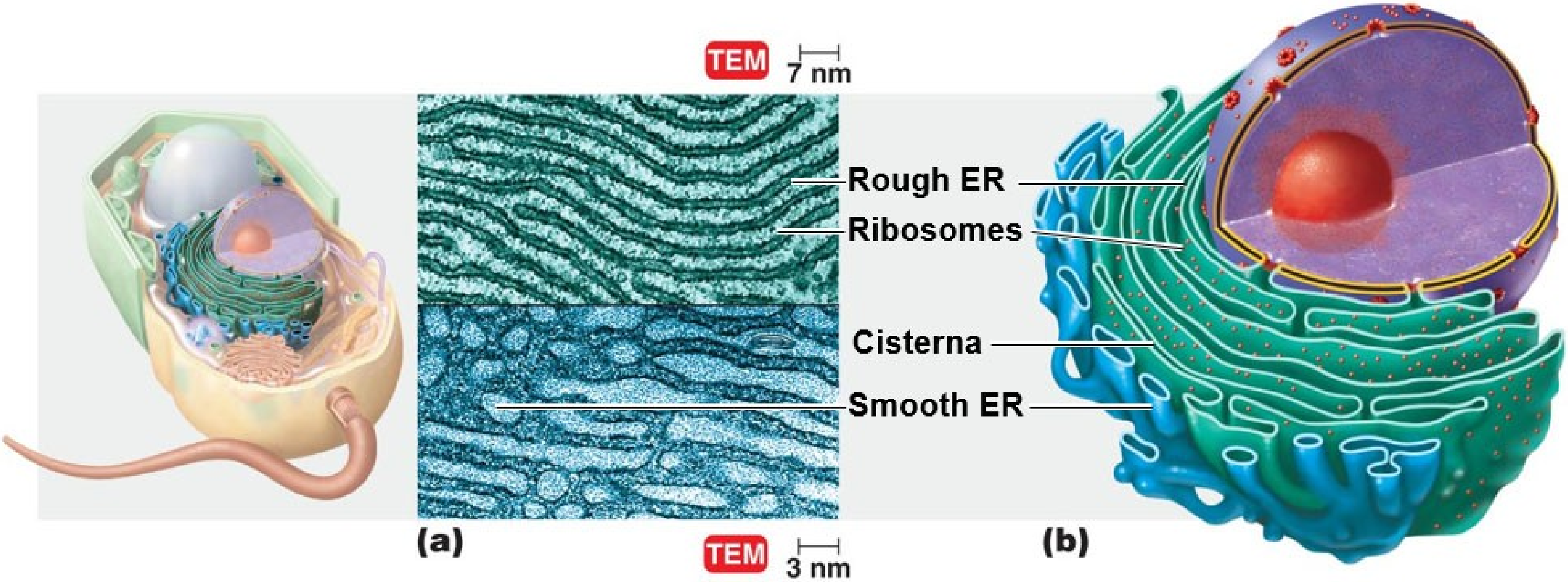
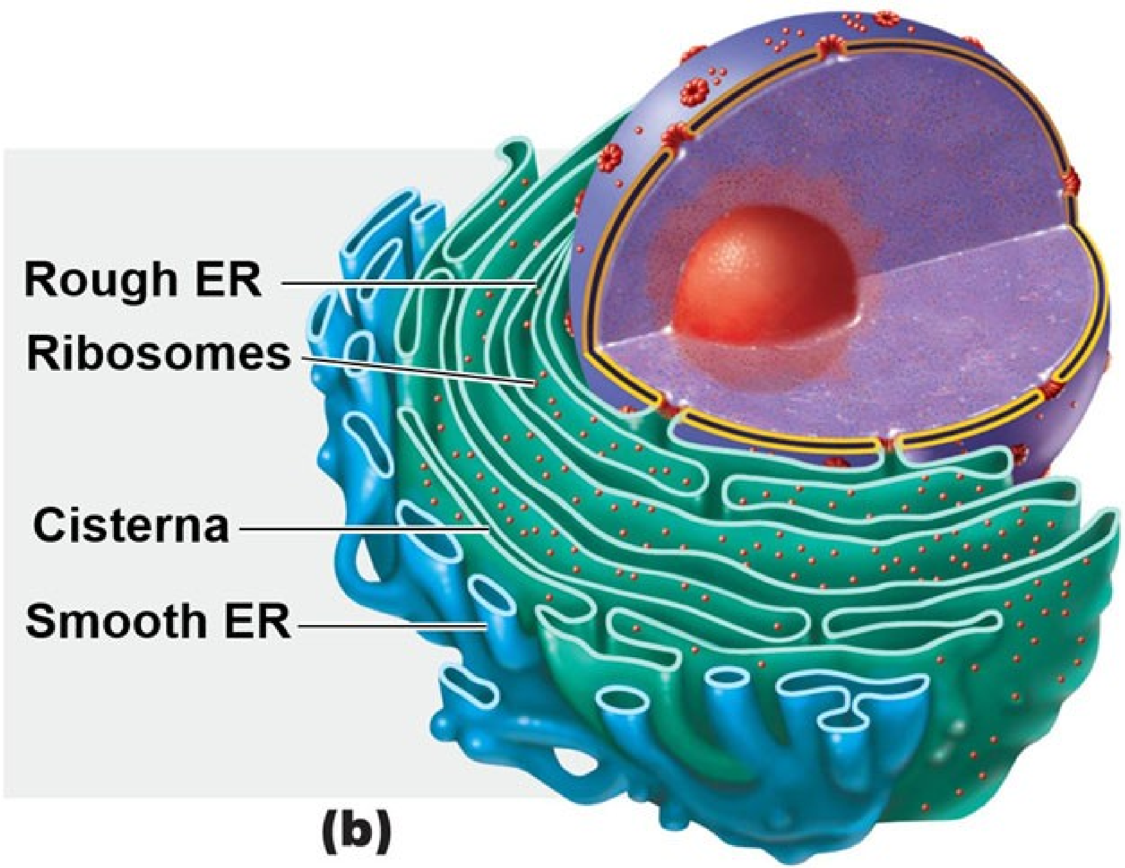


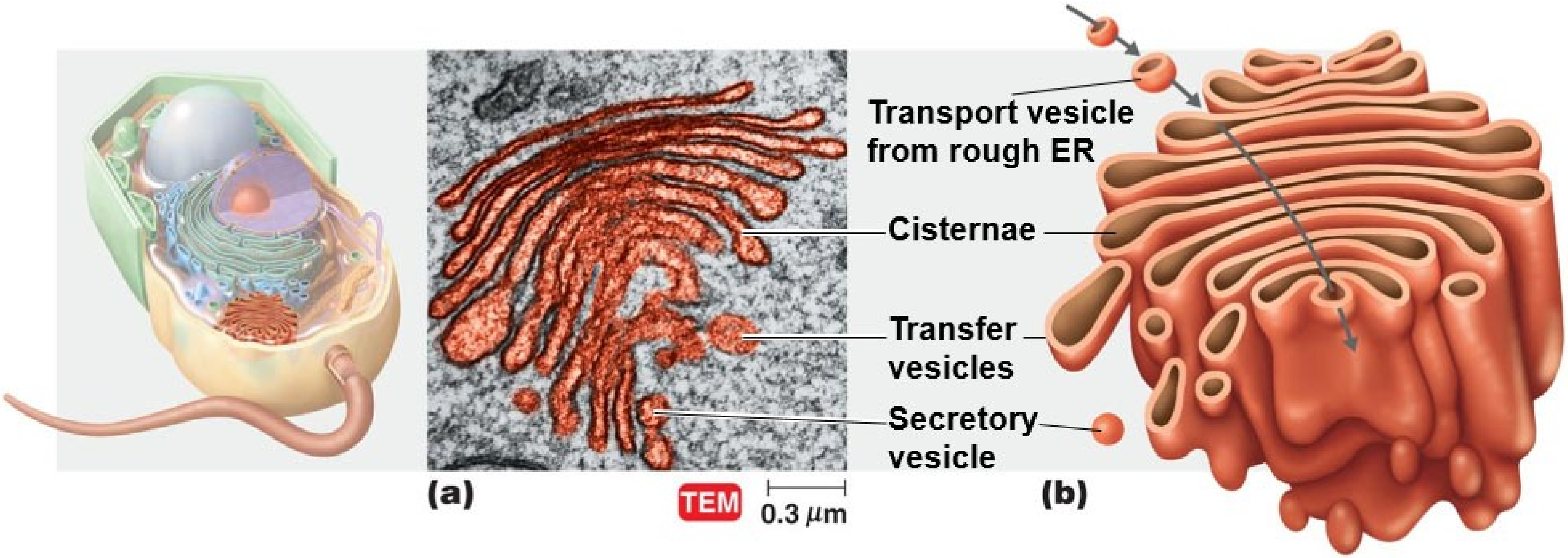
Figure 4.23b Rough Endoplasmic Reticulum and Ribosomes



Golgi Complex

- Transport organelle
- Modifies proteins from the ER
- Transports modified proteins via **secretory vesicles** to the plasma membrane

Figure 4.26 Golgi Complex



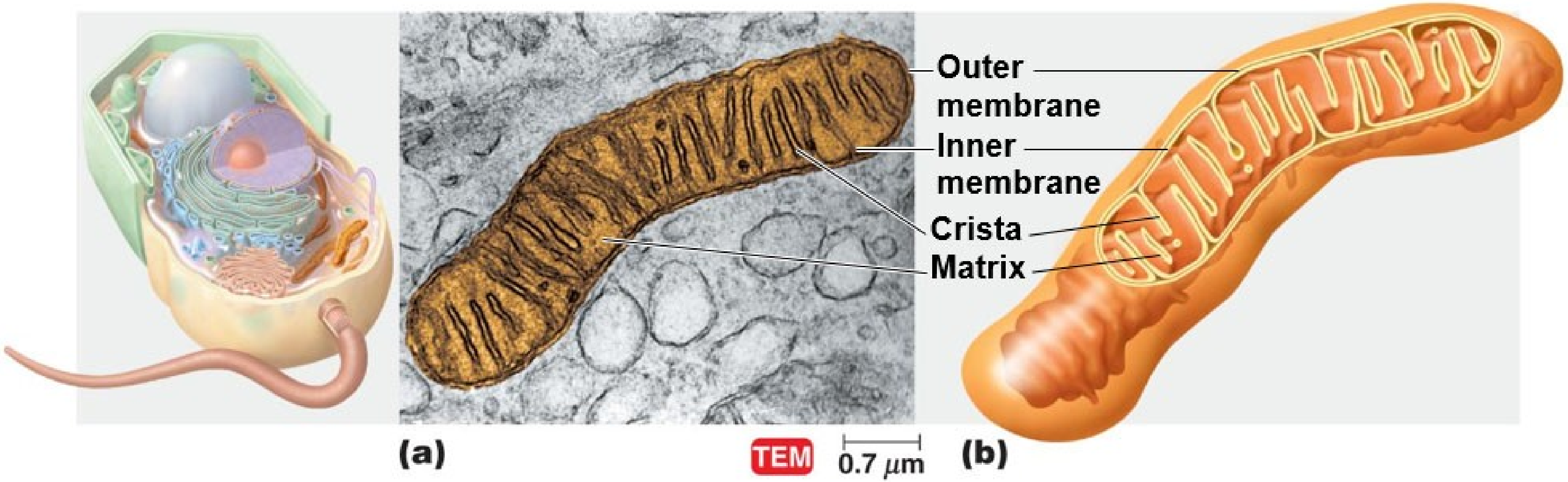
Mitochondria

- Double membrane
- Contain inner folds (**cristae**) and fluid (**matrix**)
- Involved in cellular respiration (ATP production)

Organelles (2 of 3)

- **Lysosomes**
  - Vesicles formed in the Golgi complex
  - Contain digestive enzymes
- **Vacuoles**
  - Cavities in the cell formed from the Golgi complex
  - Bring food into cells; provide shape and storage

Figure 4.27 Mitochondria



Chloroplasts

- Locations of photosynthesis
- Contain flattened membranes (**thylakoids**) that contain chlorophyll

Figure 4.28 Chloroplasts

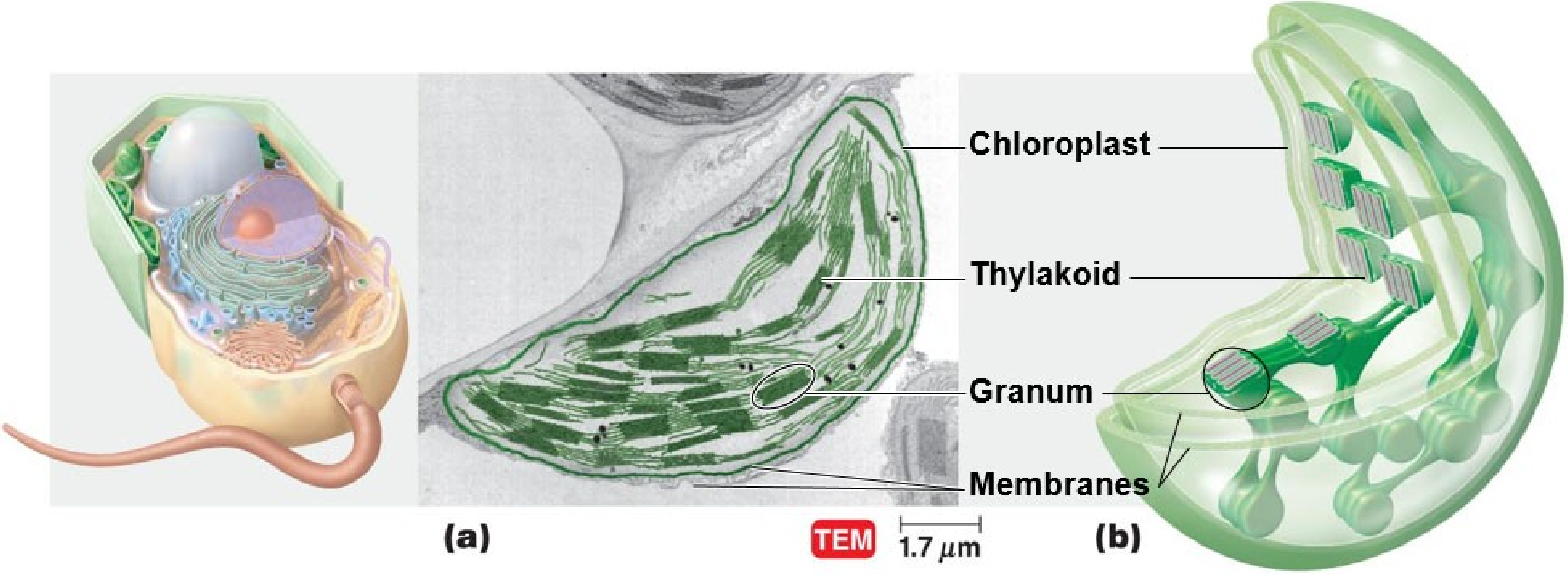
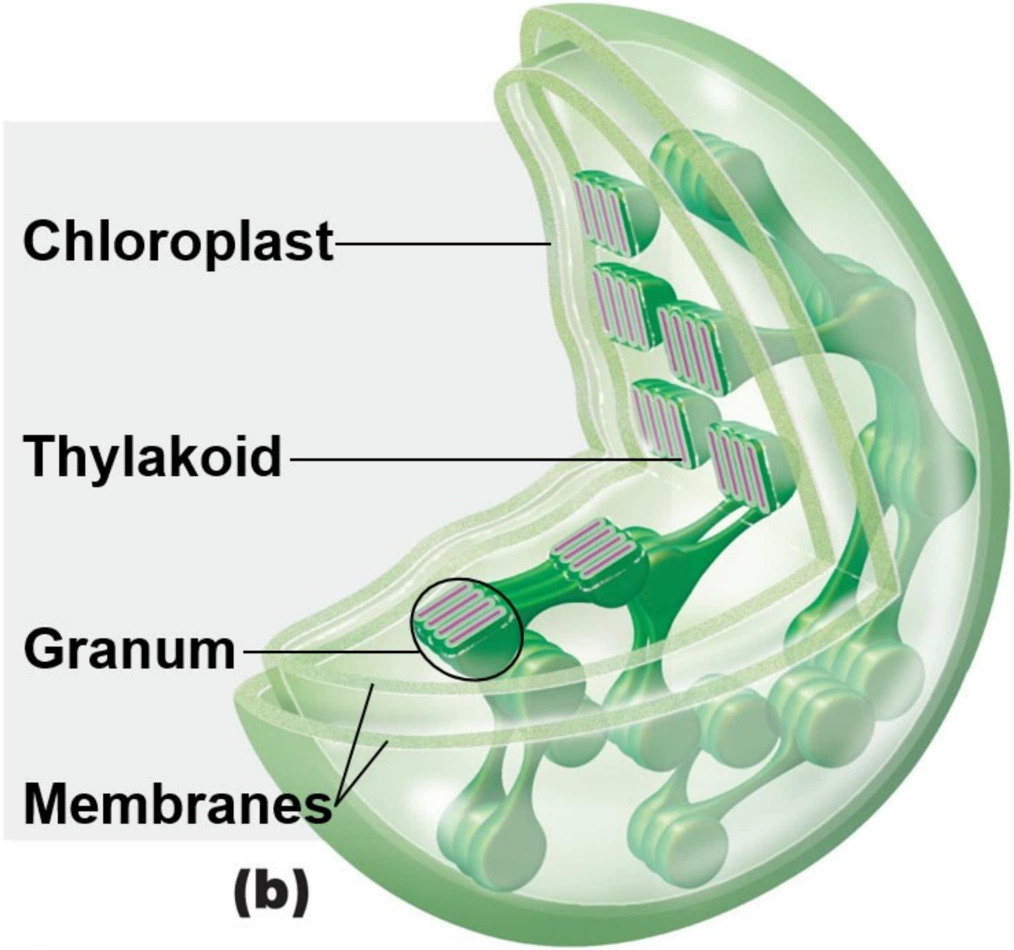


Figure 4.28b Chloroplasts



Organelles (3 of 3)

- **Peroxisomes**
  - Oxidize fatty acids; destroy H_2O_2
- **Centrosomes**
  - Networks of protein fibers and centrioles
  - Form the mitotic spindle; critical role in cell division

Check Your Understanding-8

Check Your Understanding

- ✓ Compare the structure of the nucleus of a eukaryote and the nucleoid of a prokaryote.
  4-18
- ✓ How do rough and smooth ER compare structurally and functionally?
  4-19

The Evolution of Eukaryotes (1 of 3)

Learning Objective

4-20 Discuss evidence that supports the endosymbiotic theory of eukaryotic evolution.

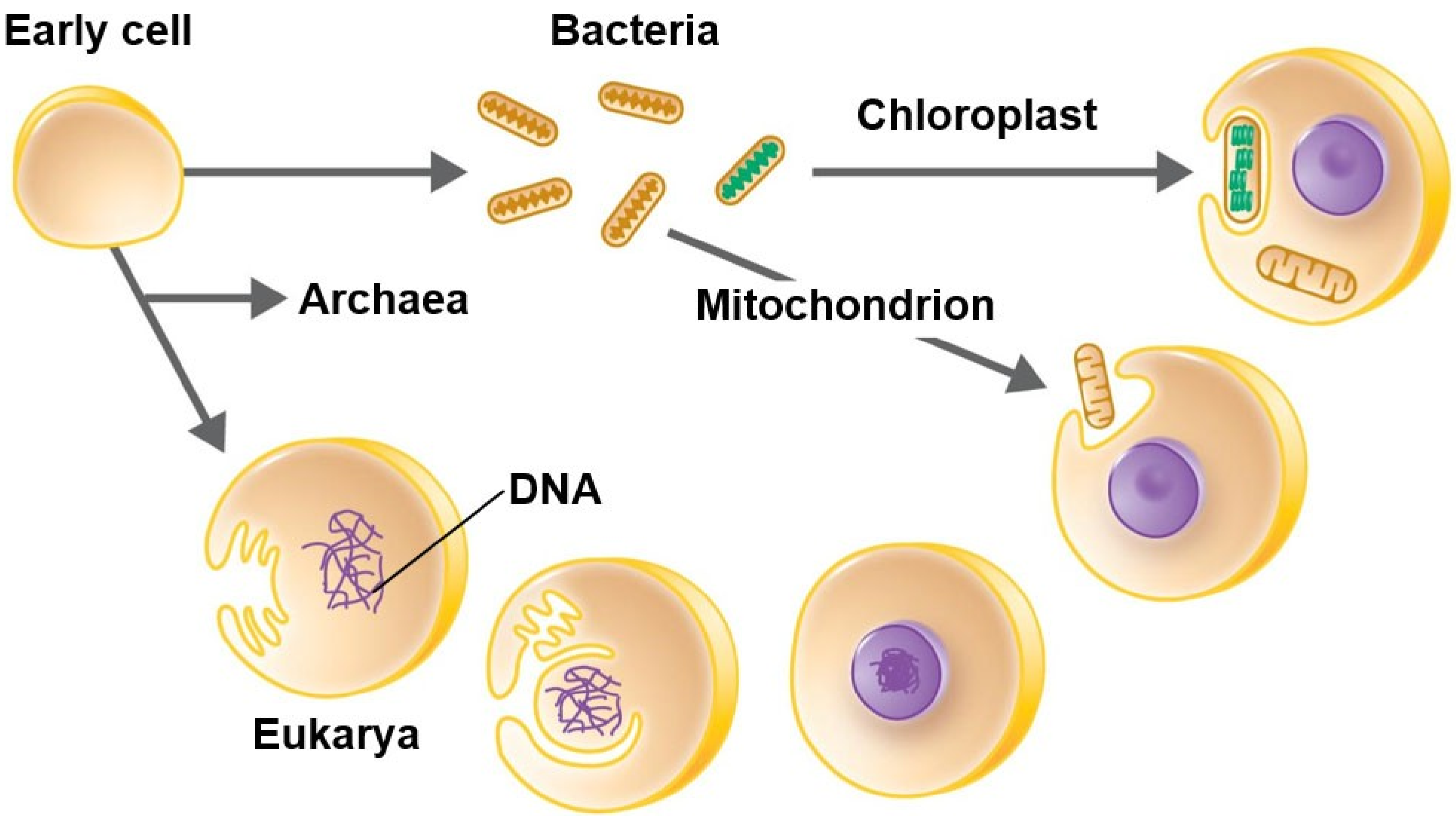
The Evolution of Eukaryotes (2 of 3)

- Life arose as simple organisms 3.5 to 4 billion years ago
- First eukaryotes evolved 2.5 billion years ago

The Evolution of Eukaryotes (3 of 3)

- **Endosymbiotic theory**
  - Larger bacterial cells engulfed smaller bacterial cells, developing the first eukaryotes
  - Ingested photosynthetic bacteria became chloroplasts
  - Ingested aerobic bacteria became mitochondria

Figure 10.2 A Model of the Origin of Eukaryotes



Check Your Understanding-9

Check Your Understanding

- ✓ Which three organelles are not associated with the Golgi complex? What does this suggest about their origin?
  4-20